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16. ABSTRACT

This report is a review of environmental levels of mercury based on published reports and other information sources. Mercury levels are reported for the atmosphere, surface and ground waters, drinking water, sediments, soil, terrestrial and aquatic biota, and man. The behavior of mercury in the environment is also discussed. Higher than ambient levels of mercury are found near mercury mines, geothermal steam fields, power plants, incinerators, sewage treatment plants, some industrialized areas, and indoors where mercury is used. The release of mercury from natural sources to air and water is double the man-related losses to these media. The levels of mercury in biota are variable, depending on food habits and environmental conditions. The highest levels occur in animals at the top of the trophic structure. Mercury levels in tissues of humans are elevated in chlor-alkali industry workers, in dentists, in people from areas with natural mercury deposits, and in urban populations as compared with the rural.

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MERCURY

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BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Vincent J. DeCarlo
Project Officer

Contract No. 68-01-1983

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF TOXIC SUBSTANCES
WASHINGTON, D.C. 20460

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PREFACE

This review of the environmental levels of mercury was conducted for the U.S. Environmental Protection Agency, Office of Toxic Substances, under Contract No. 68-01-1983. It involved (1) the review and evaluation of existing monitoring data and (2) development of an integrated data package. Information sources were identified from computerized and manual searches. Data were obrained from specialized data centers; university programs; federal programs, state programs; the Smithsonian Science Information Exchange; EPA's Storet, SAROAD, and NASN data centers; the USGS and Fish and Wildlife Service; and from readily available open literature.

Information gathered included mercury concentrations in air, surface and drinking water, groundwater, soil, food, sediment, sludge, aquatic and terrestrial organisms, human tissues, and body fluids. Details were obtained on the methods of sample collection, interferences, meteorological data, and analytical methods employed.

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EXECUTIVE SUMMARY

A determination and evaluation of environmental levels of mercury, based on a review of the literature and other information sources, is presented in this report.

The annual emission of mercury to the environment is approximately 1,525 metric tons (1973 estimate). About 4 percent of this comes from mining and smelting of mercury and other ores, 21 percent comes from manufacturing and processing operations, and 65 percent comes from the use and disposal of mercury products. The remaining 10 percent comes from inadvertent releases resulting from mercury being a contaminant in other substances, especially coal and other fuels. The major uses of mercury are in electrical apparatus and electrolytic preparation of chlorine and caustic soda.

The major portion (63 percent) of these emissions is land-destined waste, followed by air emissions (31 percent) and waterborne effluents (6 percent). The release of mercury from natural sources to air and water is double the man-related losses to these media.

The ambient concentration of mercury in urban air is in the range of 2 to 60 nanograms per cubic meter. Higher levels are observed near mercury mines and geothermal steam fields, in the plumes from power plants and incinerators, and in the environs of sewage treatment plants. Indoor air concentrations can also be elevated in laboratories and dental offices where mercury is used.

The natural background level of mercury in surface and underground water is below 0.5 ppb. In areas of mercury mineralization and in some industrialized areas, values up to a few ppb are observed. The concentrations of mercury in sediments reflect industrial inputs and are on the order of parts per million. The highest levels are found near the sediment surface.

In U.S. drinking water, mercury levels are normally less than 2 ppb.

Mercury concentrations in sludge resulting from the treatment of wastewater are of the order of a few ppm, and the variability among U.S. cities is not great. Thus, in agricultural applications of sludge, mercury has not been a great concern.

In U.S. soils not disturbed by man mercury concentrations approximate those found in rocks, 0.02 to 0.4 ppm. Higher levels are found in urban areas than in the surrounding suburbs. The mercury content of golf course soils can be up to several hundred ppm because of the use of mercurial fungicides. Croplands do not appear to have elevated mercury levels.

The levels of mercury occurring in birds and mammals are quite variable, depending on food habits and environmental conditions. Levels may vary in or between regions because of different amounts of naturally occurring mercury in the environment, its mobility in the environment, and the amounts artificially introduced. Herbivorous animals tend to have lower levels of mercury than omnivorous or carnivorous species. Granivorous species with access to mercury-coated seeds have elevated levels. Predators associated with wetlands or aquatic habitats usually have the highest mercury levels. Mercury appears to concentrate in the liver and hair or feathers.

Levels of mercury in the tissues of aquatic biota appear to be consistently highest in industrialized Atlantic coastal environs--both freshwater and marine. Regionally high values also occur in the states of the Pacific Northwest, because of both mining activity and the leaching of soils naturally high in mercury content. Other generally isolated incidences of contamination occur in many states of the U.S. These levels are most often associated with a point source of mercury emission, such as sewage treatment and chlor-alkali plants, or nonpoint source runoff from agricultural or other use of mercurial fungicides. The highest accumulations occur in fishes at the top of the trophic structure, the sport fishes and piscivores.

The behavior of mercury in the environment is complex due to its existence in three oxidation states and the fact that it reacts to form literally hundreds of compounds, both organic and inorganic. The residence times for mercury in the four compartments of the environment are: land, 1,000 years; atmosphere, 60 days; ocean, 320,000 years; and sediments 2.5×10^8 years. The terrestrial system retains approximately 50 percent of the total mercury it receives, and the remainder reaches the aquatic system through runoff and leaching. Most of the mercury reaching the soil is confined to the top 3 cm. About 1 percent is taken up by plants. The majority of all forms of mercury in water accumulate finally in bottom sediment, where they may be taken up by bottom feeders and enter the food chain. Methylmercury is synthesized in the environment by both biological and chemical processes and is the predominant form found in aquatic organisms.

The Food and Drug Administration's Total Diet Studies have provided continuous monitoring of mercury levels in foods since 1971. Of the 12 food groups examined in this program, only the meat, fish, and poultry composite has regularly contained measurable amounts of mercury. The 11 remaining food groups have generally contained less than 0.01 ppm mercury. "Market-basket"-type surveys in which a great variety of foods are examined indicate that mercury concentrations in foods other than meats, fish, and poultry products are very low or nondetectable.

Estimates of daily dietary intake of mercury obtained from FDA's Total Diet Studies for the years 1971-1974 were constant, averaging about 3 μg/day over the 4-year period.

Mercury levels in tissues of both normal and exposed humans show considerable variation. Data from localized studies suggest "normal" mercury levels of 0.005 ppm in whole blood, 10 ppm in hair, below 1 to 3 ppm in kidney, and below 0.75 ppm in liver. Higher levels are reported in chlor-alkali industry workers, in dentists, in people from areas with natural mercury deposits, and in urban populations as compared with the rural.

Biological half-lives vary considerably depending upon the chemical form of the mercury and also according to whether the half-life is based upon the whole body or single organs or tissues. Inorganic forms have the shortest half-life, probably because of their relatively poor absorption and because their attachment to the plasma proteins of the blood (rather than the erythrocytes) permits rapid excretion from the body by the urine. The biological half-life of inorganic mercury in blood has been estimated at 20 days, while for the whole body, about 40 days seems appropriate. In comparison, vapor and alkylmercurials are more efficiently absorbed and cross the blood-brain barrier, permitting fixation and accumulation in the brain tissue. Tracer studies of human volunteers following inhalation of radioactiver mercury vapor have revealed a whole-body half-life of about 58 days.

Biological half-lives in kidney and brain are substantially longer than those for the whole body for all forms of mercury. Evidence from primate studies suggests that the half-life of mercury in the brain is probably on the order of years.

The whole-body half-life of methylmercury in man is about 70 to 80 days. Tracer studies, calculations from decay curves following the elimination of methylmercury from the diet, and similar calculations based on the distribution of mercury in hair of poisoned individuals confirm this range.

Absorption of methylmercury from the gastrointestinal tract is almost 100 percent complete. In addition, efficient mechanisms of transport across the blood-brain barrier, affinity of alkylmercurials for neurological tissue and a long half-life permit accumulations in the brain when intake of mercury is chronic. In view of the mechanism of biotransformation, a potential for methylmercury contamination of the food chain exists whenever mercury is discharged into food-producing waters.

1. INTRODUCTION

Although mercury (Hg) is a rare element, ranking 16th from the bottom of the list in abundance of elements in the earth's crust (Goldwater, 1971), its unique properties have led to a number of specialized but important uses by man. These uses, plus the natural release of mercury from ore bodies, make mercury an ubiquitous element occurring throughout the environment (in rocks, soil, water, and air, as well as in plant and animal tissues).

PHYSICAL AND CHEMICAL PROPERTIES

Mercury is one of the heaviest metals with a specific gravity of 13.5 compared with 11.35 for lead. It is the only metal liquid at ordinary room temperatures, having a freezing point of -40 C (-40 F) and a boiling point of 357 C (674 F). It has a high vapor pressure, 0.002 mm of Hg at 26 C (79 F), so that atmospheric concentrations at ordinary room temperatures are of concern. The most common ore of mercury is cinnabar, mercuric sulfide, which is easily reduced by heating to liberate elemental mercury. As a liquid, mercury is handled in flasks with the standard industrial unit for production, consumption, and pricing statistics being a 76-pound (34.5 kg) flask.

Mercury is found in three valence states: Hg(0), Hg(I), and Hg(II), and forms hundreds of compounds, both inorganic and organic; the metal reacts with a wide variety of oxidizing agents to form Hg(I) and Hg(II) compounds and, not infrequently, mixtures of the two.

The most important mercury compounds from an environmental viewpoint may be categorized into five groups:

(1) Metallic mercury - liquid and vapor
(2) Inorganic salts - sulfides, chlorides, nitrates, and oxides
(3) Alkyl compounds - those containing methyl or ethyl radicals
(4) Alkoxyalkyl compounds - usually complexes
(5) Aryl compounds - particularly phenymercurials.

PRODUCTION AND USES OF MERCURY

Most commercial U.S. mercury deposits are found in the far western states, primarily in Nevada and California (Figure 1.1). Estimated U.S. reserves represent only about 8 percent of the estimated world mercury reserves of 180,000 tons (Cammarota, 1975). Principal producing nations

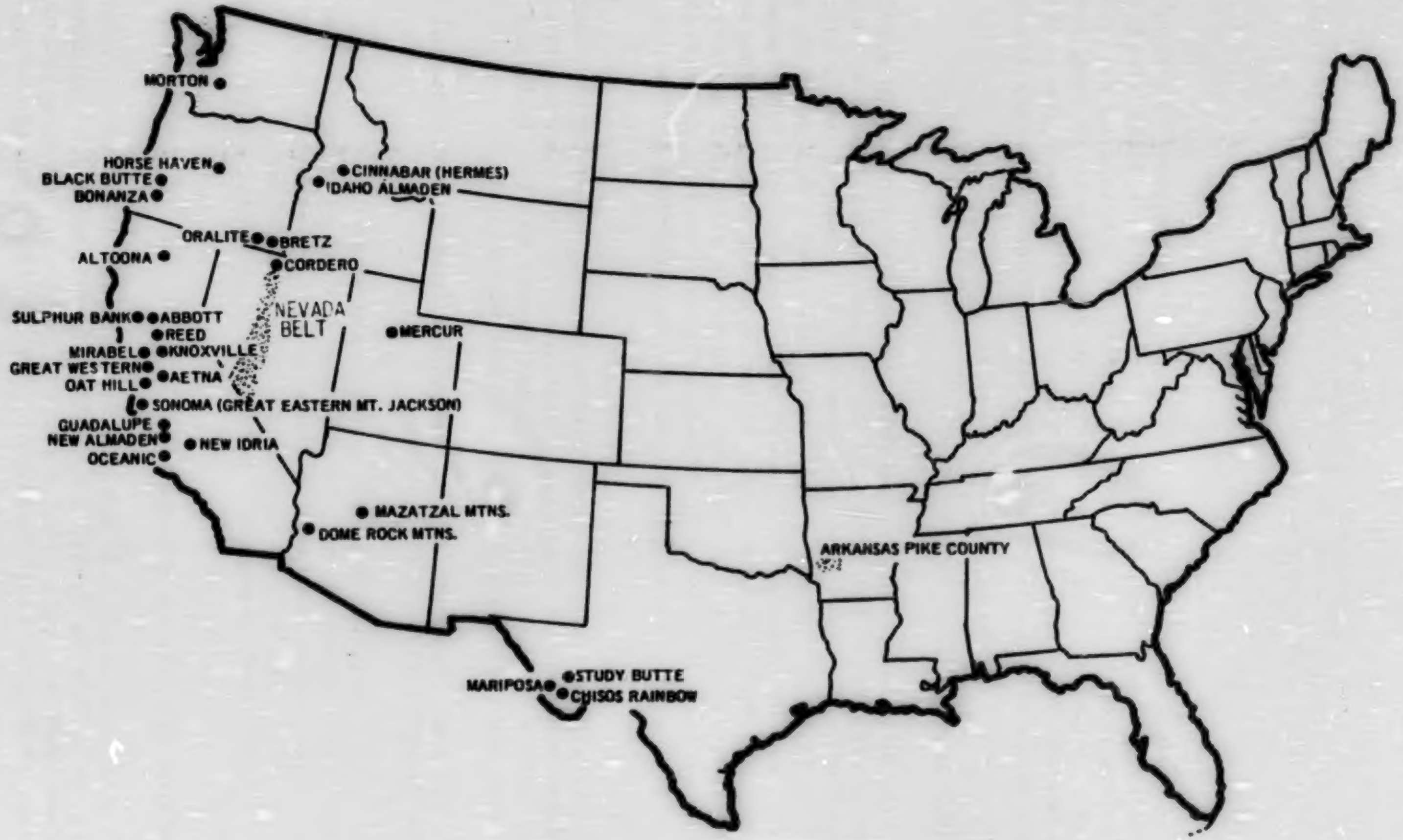

MORTON
HORSE HAVEN
BLACK BUTTE
BONANZA
CINNABAR (HERMES)
IDAHO ALMADEN
ORALITE
BRETZ
CORDERO
ALTOONA
NEVADA BELT
SULPHUR BANK
ABBOTT
REED
MERCUR
MIRABEL
KNOXVILLE
GREAT WESTERN
AETNA
OAT HILL
SONOMA (GREAT EASTERN MT. JACKSON)
GUADALUPE
NEW ALMADEN
NEW IDRIA
OCEANIC
MAZATZAL MTNS.
DOME ROCK MTNS.
ARKANSAS PIKE COUNTY
STUDY BUTTE
MARIPOSA
CHISOS RAINBOW

Figure 1.1. Commercial U.S. mercury deposits.

are Algeria, Italy, Spain, Mexico, Turkey, Yugoslavia, and the USSR. The U.S. is a net importer of mercury, and domestic primary production is limited to a small number of mines (Smith, 1976). The number of mines has decreased drastically in recent years, reflecting the gradual depletion of economically recoverable ores in the U.S. The declining importance of U.S. primary production is illustrated in Table 1.1 which shows operating mines and mercury production for the past several years.

TABLE 1.1. UNITED STATES DOMESTIC MERCURY PRODUCTION

	1971	1972	1973	1974	1975[a]
Number of producing mines	56	89	24	10	3
Production, metric tons	616	253	77	75	233
Production, number of flasks	17,883	7,349	2,227	2,189	6,750
Price per flask in New York (duty paid)	$292.41	$218.28	$286.23	$281.69	$160.00

Source: U.S. Bureau of Mines, 1976.

[a] U.S. Bureau of Mines estimate.

The large increase in 1975 resulted from the opening of a major new mine at McDermitt, Nevada, which has an annual capacity of 20,000 flasks. Only two other mines were in operation in 1975, and present depressed prices for mercury make it unlikely that U.S. production will increase significantly in the near future. It is evident from these data that losses of mercury to the environment associated with mining and extraction have declined in importance in recent years.

Mercury consumption, by use, is given in Table 1.2 for the 1965-1975 period. The major uses have been in electrical apparatus and electrolytic preparation of chlorine and caustic soda (chlor-alkali). Together, these two uses accounted for 61 percent of U.S. consumption in 1975.

The trend in mercury consumption in the U.S. has been downward since the mid-sixties, primarily as a result of the recognition of its environmental hazards. Agricultural uses have declined significantly and are expected to continue to decline. Mercury catalysts are used in the production of several plastics and synthetics; alternatives include organotins. Use in dental preparations, electrical apparatus, and paints is expected to increase with increasing population and Gross National Product (GNP). Use

TABLE 1.2. CONSUMPTION OF MERCURY IN THE UNITED STATES
(in number of flasks)

End Use	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975[a]
Agriculture	3,116	2,374	3,732	3,430	2,689	1,811	1,477	1,836	1,830	980	600
Amalgamation	268	248	219	267	195	219					
Catalysts	924	1,932	2,489	1,914	2,958	2,238	1,012	800	673	1,298	689
Dental preparations	3,196	2,133	2,386	3,079	2,880	2,286	2,361	2,983	2,679	3,024	1,773
Electrical apparatus	18,887	17,638	16,223	19,630	18,490	15,952	16,885	15,553	18,000	19,678	16,235
Electrolytic preparation of chlorine and caustic soda	8,753	11,541	14,306	17,453	20,720	15,011	12,154	11,519	13,070	16,897	15,223
General laboratory use	2,332	2,217	1,940	1,989	1,936	1,806	1,798	594	658	476	278
Industrial and control instruments	10,330	7,294	7,459	7,978	6,655	4,832	4,871	6,541	7,155	6,202	4,102
Paint: antifouling	255	140	152	392	244	198	414	32	32		
Paint: mildew-proofing	8,211	8,789	7,026	10,174	9,486	10,149	8,191	8,190	7,571	6,807	6,926
Paper and pulp manufacture	619	612	446	417	558	226	2	1			
Pharmaceuticals	418	232	283	424	712	690	682	578	606	597	431
Other	16,251	16,359	12,856	8,275	9,134	6,085	2,410	4,280	2,009	3,514	1,735
Total, Flasks	73,560	71,509	69,517	75,422	77,372	61,503	52,257	52,907	54,283	59,479	51,105
Metric Tons	2,538	2,467	2,398	2,602	2,669	2,122	1,803	1,825	1,872	2,052	1,763

Sources: Van Horn (1975); Cammarota (1975).

[a] Preliminary.

in chlor-alkali cells may remain essentially around present levels on a replacement basis for consumption in present cells. Chlor-alkali production capacity expansion is estimated to be more likely via diaphragm cells than mercury cells.

The downward trend in total mercury consumption is not expected to continue. Projected consumption for 1985 has been estimated by the U.S. Bureau of Mines, as reported by Van Horn (1975) and shown in Figure 1.2. High and low ranges are by the Bureau of Mines; superimposed are "most probable" estimates by Van Horn. The U.S. Bureau of Mines (Cammarota, 1975) subsequently estimated projected consumption for the year 2000 broken down into six principal use categories, as shown in Figure 1.3. This projection modifies some of the 1985 estimates. Use in electrical apparatus, primarily batteries and mercury lamps, is estimated to increase to probably 25,000 flasks/year, and perhaps as much as 30,000. At the same time, estimates of mercury usage in instruments and in paints have been reduced. Use in instruments is estimated to range between 4,000 and 9,000 flasks. Use in paints is projected to range between zero and 11,000 flasks, depending on the extent of control or prohibition of this use. Either demands for "other" uses remain about the same, but others now include pharmaceuticals, catalysts, and agricultural uses. Total use is estimated to range between 39,000 and 82,000 flasks, with the most probable value around 58,000 flasks. This is nearly the same as Van Horn's most probable estimate of about 61,000 flasks for 1985 and very close to the average annual consumption for the years 1970 through 1975 (55,000 flasks).

SOURCES OF ENVIRONMENTAL CONTAMINATION BY MERCURY

Mercury may enter the environment by a variety of routes: through man's use of the metal in chlor-alkali production, in electrical equipment, and in mildewicides and fungicides, etc.; through the combustion of fossil fuels and the smelting of nonferrous metals; and from natural sources such as ore deposits and geothermal steam fields. Release to the atmosphere around ore deposits occurs because of the volatility of mercury.

Estimates of 1973 mercury losses, tabulated according to Standard Industrial Classification (SIC) grouping have been published by the U.S. Environmental Protection Agency (Van Horn, 1975) and are reproduced in Table 1.3.

In 1973, the total man-related losses in the U.S. were an estimated 1,525 metric tons, of which 31 percent was lost to the atmosphere, 6 percent to water, and 63 percent to land. Comparable amounts, 1,200 metric tons, were released to the environment from natural sources (85 percent to the atmosphere and 15 percent to water). The release of mercury from natural sources to air and water was double the man-related losses to these media.

Losses through the combustion of fuel may be higher than those shown in this estimate. According to Spittler (1976), experience is pointing to

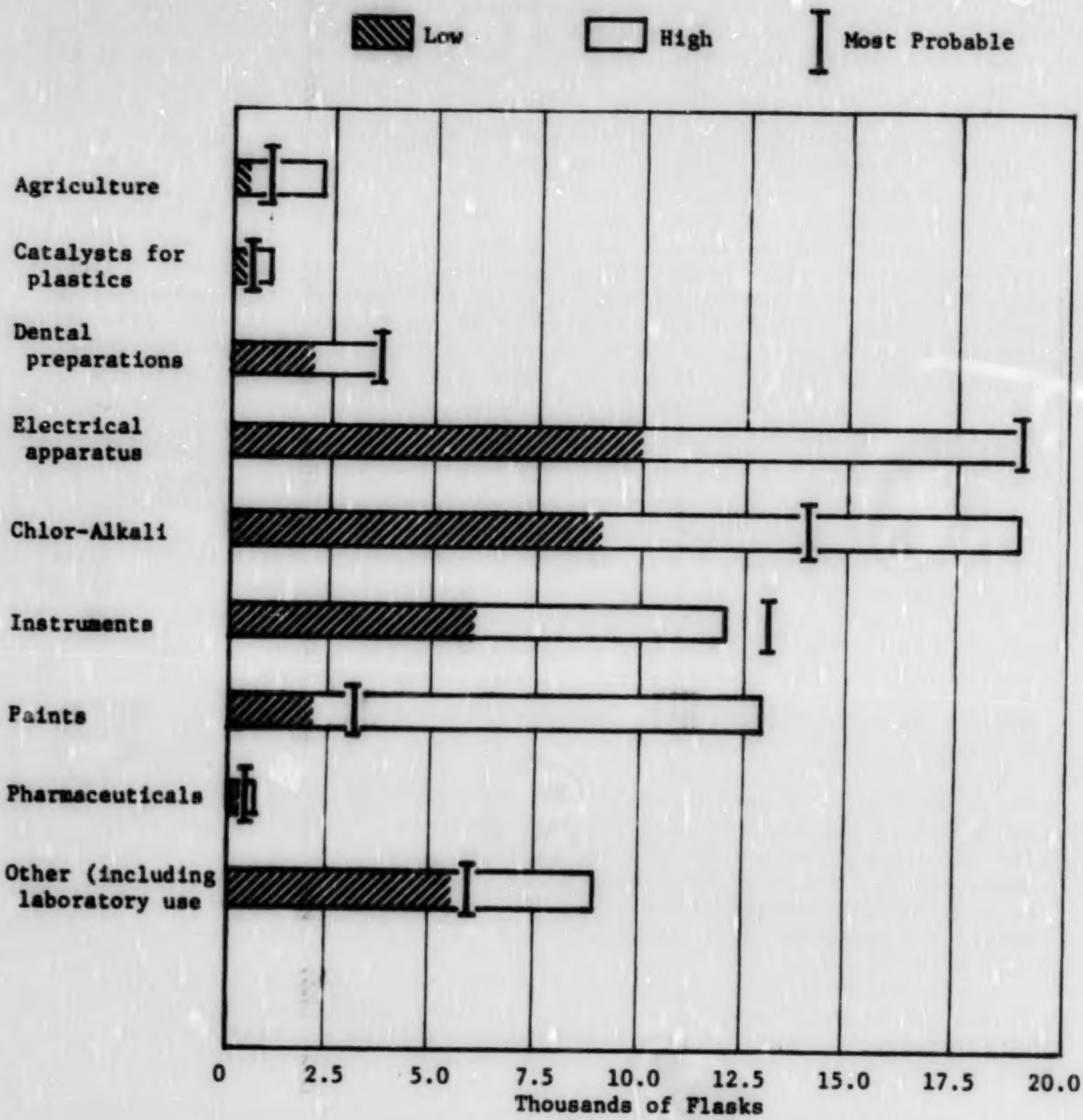


Figure 1.2. Projected mercury consumption in the United States by end use, 1985 (Van Horn, 1975).

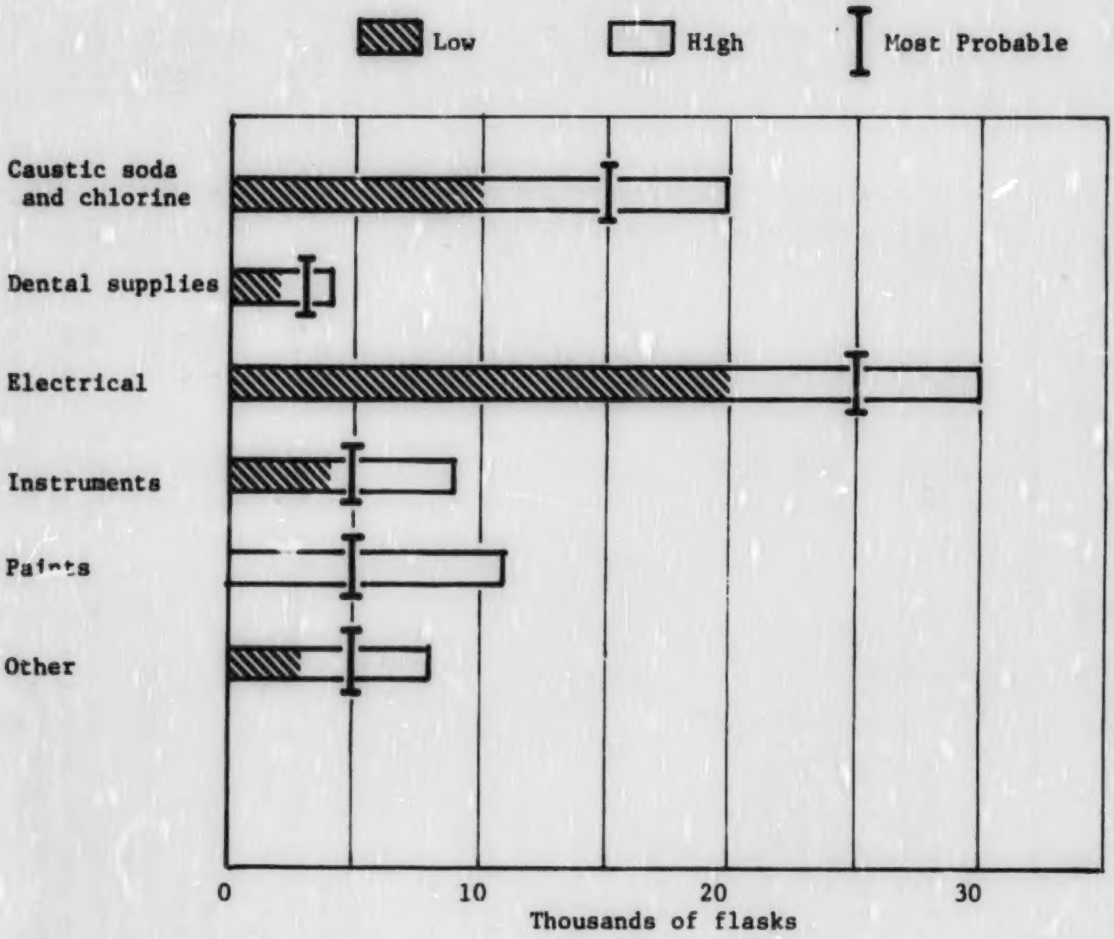


Figure 1.3. Projected mercury consumption in the United States by end use, Year 2000 (Cammarota, 1975).

TABLE 1.3. TOTAL MERCURY LOSSES IN 1973 FOR CONTERMINOUS U.S. BY SECTOR AND SIC CATEGORY
(in thousands of kilograms)

Sector	SIC No.	Description	Total Losses to			Total Mercury Lost	Total Recycled
			Air	Water	Land		
I		Mercury Mining and Smelting					
	1092M	Mercury mining	0.01	0.00	0.01	0.02	0.00
	1092P	Mercury processing (including secondary)	7.84	0.00	0.41	8.25	0.00
		Subtotals	7.85	0.00	0.42	8.27	0.00
			(1.7%)	(0.0%)	(0.0%)	(0.5%)	(0.0%)
II		Other Mining					
	1021	Copper mining	0.02	0.01	0.08	0.11	0.00
	1031	Zinc and lead mining	0.00	0.00	0.01	0.01	0.00
	3331	Copper smelting	40.77	2.26	2.26	45.29	0.00
	3333	Zinc smelting	4.59	0.25	0.25	5.09	0.00
	3241	Cement processing	0.50	0.25	1.76	2.51	0.00
	3274	Lime processing	0.08	0.04	0.29	0.41	0.00
	3332	Lead smelting	4.75	0.26	0.26	5.27	0.00
		Subtotals	50.71	3.07	4.91	58.09	0.00
			(10.8%)	(3.5%)	(0.5%)	(3.8%)	(0.0%)
III		Unregulated Sources					
	021	Livestock	0.00	0.0	17.70	17.70	0.00
	2911C	Fuel oil-residential, commercial, commercial, industrial	16.94	0.00	0.02	16.96	0.00
	2911M	Refineries	1.15	0.00	1.15	2.30	0.00
	2951C	Tars and asphalt	1.10	1.67	14.99	17.76	0.00
	3312M	Coke ovens	7.16	0.51	2.56	10.23	0.00
	4091C	Coal-residential, commercial, industrial	9.97	0.00	1.11	11.08	0.00
	49110	Utilities-oil and natural gas	11.99	0.00	0.01	12.00	0.00
	4924C	Natural gas-residential, commercial, industrial	15.46	0.00	0.01	15.47	0.00

TABLE 1.3 (Continued)

Sector	SIC No.	Description	Total Losses to Air	Total Losses to Water	Total Losses to Land	Total Mercury Lost	Total Recycled
III		Unregulated Sources (Cont'd)					
	4911C	Utilities-coal	40.71	0.00	4.52	45.23	0.00
		Subtotals	104.48 (22.2%)	2.18 (2.5%)	42.07 (4.4%)	148.73 (9.8%)	0.00 (0.00%)
V		Manufacturing and Processing					
	2.5B	Caustic	0.00	7.61	1.90	9.51	0.00
	2819M	Catalyst manufacture	0.00	0.02	0.00	0.02	0.00
	2851M	Paint manufacture	0.01	0.20	0.05	0.26	0.00
	2879M	Pesticide manufacture	0.00	0.06	0.00	0.06	0.00
	2833M	Pharmaceuticals manufacture	0.00	0.02	0.00	0.02	0.00
	2812	Chlor-alkali	14.84	2.93	226.83	224.60	0.00
	2261	Textiles	0.00	0.15	7.63	7.78	0.00
	2851F	Paint formulation	0.29	0.35	0.00	0.64	0.00
	38291M	Control instrument manufacture	0.00	0.00	1.97	1.97	1.97
	3079P	Catalyst usage	0.05	0.10	18.85	19.00	0.00
	3.0	Other	10.28	10.23	8.70	29.21	20.66
	3629M	Tubes/switches manufacture	0.00	0.00	1.57	1.57	0.00
	36410M	Lamp manufacture	0.40	0.00	1.34	1.74	0.00
	36420M	Battery manufacture	0.13	0.05	2.49	2.67	0.00
		Subtotals	26.00 (5.5%)	21.72 (24.8%)	271.33 (28.1%)	319.05 (21.0%)	20.66 (14.1%)
VIIIA		Final Consumption: Commercial and Industrial					
	2.5A	Urethane and miscellaneous	0.12	0.00	2.22	2.34	0.00
	2879N	Nonagricultural pesticide use	4.39	17.56	21.95	43.90	0.00
	2879A	Agricultural pesticide use	0.00	2.83	16.02	18.85	0.00
	38291C	Control instrument consumption	16.54	0.00	107.50	124.04	82.69
	36292C	Tubes/switches consumption	7.53	0.00	46.26	53.79	0.00
	2641C	Lamp consumption	6.07	0.00	37.31	43.38	0.00

TABLE 1.3 (Continued)

Sector	SIC No.	Description	Total Losses to Air	Total Losses to Water	Total Losses to Land	Total Mercury Lost	Total Recycled
VIIIA		Final Consumption: Commercial and Industrial (Cont'd)					
	7391	Laboratory usage	2.28	5.92	1.59	9.79	12.98
		Subtotals	36.93	26.31	232.85	296.09	95.67
			(7.8%)	(30.0%)	(24.1%)	(19.4%)	(65.2%)
VIIIB		Final Consumption: Consumer Goods					
	2834C	Pharmaceuticals consumption	1.07	17.77	2.09	20.90	0.00
	2851C	Paint consumption	173.61	0.00	9.14	182.75	0.00
	36420C	Battery consumption	69.71	0.00	403.30	473.01	24.89
	8021	Dental applications	0.93	16.65	0.00	17.58	5.55
		Subtotals	245.29	34.42	414.53	694.24	30.44
			(52.0%)	(39.2%)	(42.9%)	(45.5%)	(20.7%)
Total			471.26	87.70	966.11	1,525.07	146.77
Final Disposal							
Sewage			4.01	19.92	22.88	46.80	
Urban runoff			0.00	11.70	0.00	11.70	
Natural Sources							
Degassing			1,018.70	0.00	0.00	1,018.70	
Runoff and groundwater			0.00	188.30	0.00	188.30	

Source: Van Horn, 1975. Further refinements (as yet unpublished) have been made in these data, but the changes are small, ±5 percent.

combustion processes (coal and municipal or industrial wastes) as a chief source of ambient mercury. In a discussion of fossil fuels as a source of mercury pollution, Joensuu (1971) pointed out that, although the concentration of mercury in fuels is small, fuels are consumed at an enormous rate, consequently, they must be considered as a possible significant source of mercury released into the environment.

Joensuu presented analyses for 36 American coals. Mercury concentrations ranged from 0.07 to 0.08 ppm in some West Virginia coals to 20 to 30 ppm in other West Virginia and Wyoming coals. Average of a large number of Illinois coals was reported as 0.21 ppm (Ruch et al., 1971). If the nominal average for coals burned in the U.S. is assumed to be 0.5 ppm, the average annual consumption of 545 million metric tons (600 million tons) may release up to 270 metric tons (300 tons) of mercury to the environment.

The available data indicate that almost all of the contained mercury will be emitted to the air. Billings et al. (1973) determined a mercury material balance on a large pulverized coal-fired utility boiler, finding that over 95 percent of the mercury in the coal (0.3 ppm average) was emitted into the flue gases. Similar results were obtained by Klein and Andren (1975) in their investigation of the Allen Steam Plant of the Tennessee Valley Authority and by Anderson and Smith (1977) on the basis of a year's observations of an Illinois power plant. Thus, mercury input to the environment from the combustion of coal is an important source of ambient mercury.

Trends in relative mercury losses to the environment have been projected by Van Horn (1975), as illustrated in Figure 1.4. Discharges to water have already decreased significantly and this trend will continue. Discharges to air have increased somewhat. This is due primarily to the increased use of fossil fuels with higher mercury content, and this is expected to continue to increase. Industrial discharges to land have increased sharply, as the land has become the recipient of much of the material previously discharged to water.

The resulting trends in the observed concentrations of mercury in the various environmental media are not so easily deduced. This is due not only to deficiencies in available data but also to the fact that mercury emissions from natural sources are comparable to man-related emissions. Natural emissions to air and water are double the man-related discharges to these media and could mask small changes resulting from man's activities.

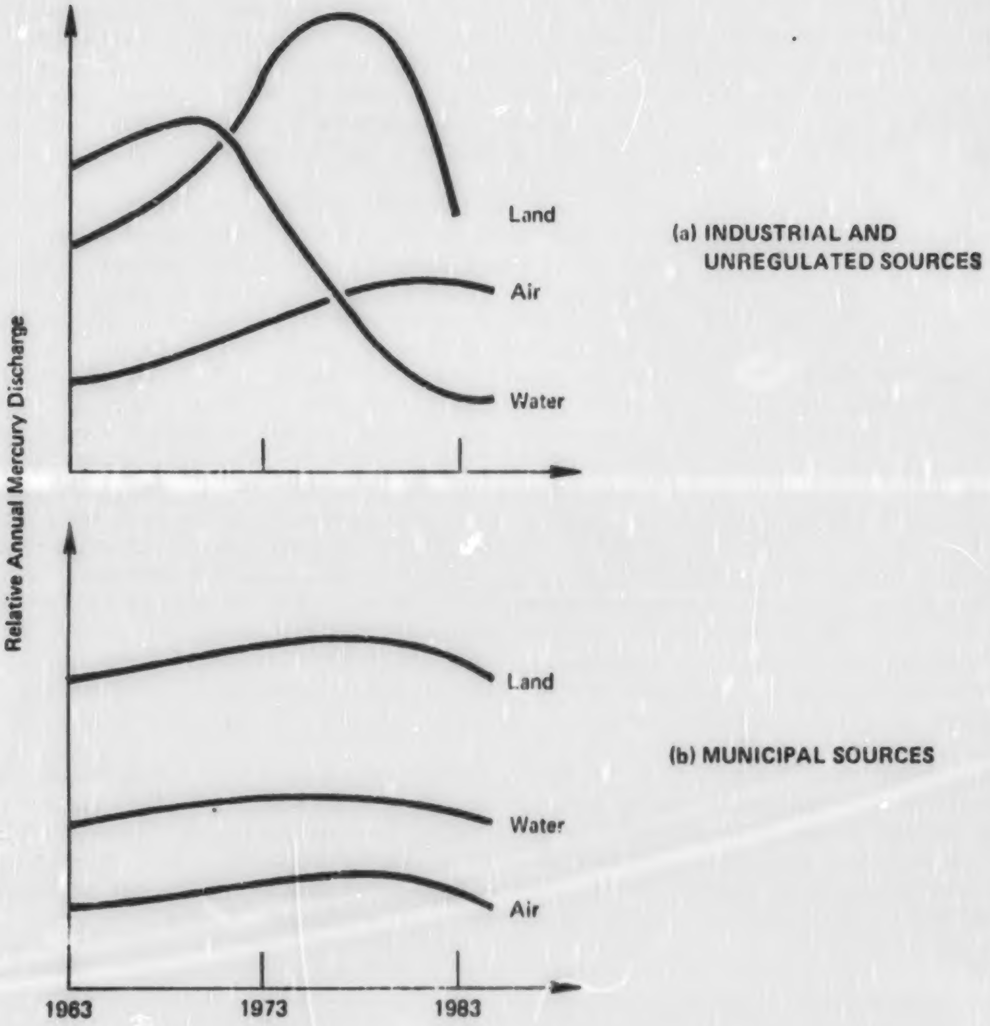


Figure 1.4. Past and probable future trends in final disposal of mercurials (Van Horn, 1975).

2. MERCURY LEVELS IN THE ENVIRONMENT

AIR

National Atmospheric Monitoring Programs

Concentrations of mercury in the atmosphere have not been measured on a national basis. Mercury concentrations are not included in National Air Surveillance Networks (NASN) reports, nor were data found in the U.S. Environmental Protection Agency Storage and Retrieval of Aerometric Data (SAROAD) computer file. The apparent reason for this omission is that although atmospheric mercury may be largely associated with particulate matter, some may be present as vapor. Additionally, the high ventilation rates associated with the collector of a Hi-Vol particulate sample may rerelease trapped mercury back to the atmosphere. Although atmospheric mercury concentrations based on Hi-Vol sampling have been reported, they are of dubious value (Spittler, 1976). Such results would appear to be biased on the low side.

Approximate ranges of mercury vapor concentrations in ambient air drawn from Goldwater's (1971) overview paper were summarized by Cooper et al. (1974) as follows:

Type	Location	Mercury Concentration, ng/m^3
Outdoor	Background	1 - 5
	Urban	2 - 60
Indoor	Indoor	100 - 200
	Laboratory	200 - 10,000
	Dental office	10,000 - 100,000

While not national averages, these appear to well represent the results from a variety of localized investigations.

The explanation for the concentrations found in places which use metallic mercury (laboratories and dental offices) is the high vapor pressure of mercury. The vapor pressure increases rapidly with temperature, approximately doubling for every 10 C increase. The theoretical saturation concentrations of mercury in air have been calculated by Stahl (1969). As illustrated by Figure 2.1, at normal ambient temperatures these are in the range of 5 to 20 milligrams per cubic meter. While saturation is an unlikely concentration, these values are illustrative of the possibilities of reaching

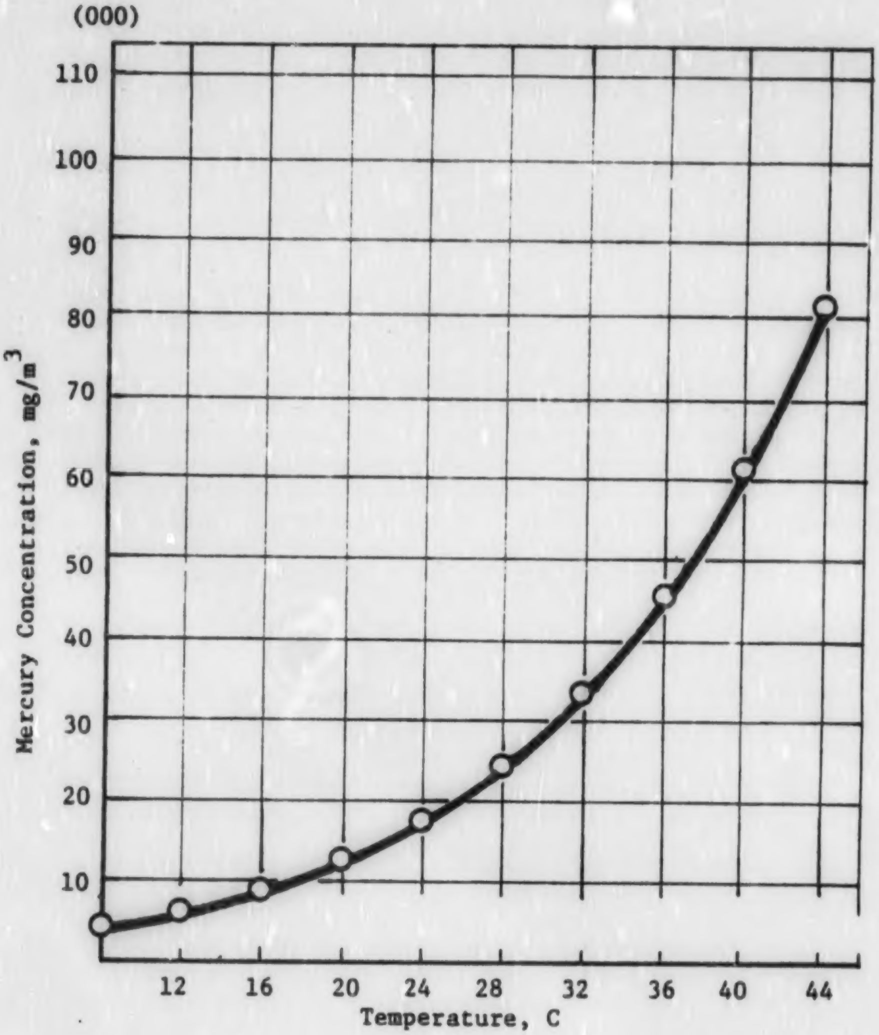


Figure 2.1. Theoretical saturation concentrations of mercury in air (Stahl, 1969).

elevated concentrations in unventilated rooms which are contaminated with mercury.

Local Monitoring of Atmospheric Mercury Concentrations

Although there have been a few localized monitoring efforts in the 1970's there is still a paucity of data.

Sampling and analytical methods and procedures have contributed to the lack of reliable data on mercury concentrations in air. As noted in the preceding section, some of the local investigations have been based on the analysis of Hi-Vol particulate samples.

Some investigators absorbed mercury from the air in iodine monochloride (ICl) solutions, an EPA standard method. The initial version of the method was found to give both imprecise and inaccurate results (Mitchell and Midgett, 1976). The method has been modified and improved by these same investigators to give satisfactory results; however, the reliability of earlier results obtained by this method may be suspect.

The preferred method for detecting mercury concentrations in air at the nanogram per cubic meter level now appears to be based on the trapping of mercury as an amalgam on silver wool or on a gold screen. The use of two duplicate air streams permits the collection of elemental mercury on silver wool in one side; a pyrolyzer converts mercury compounds in the other stream to elemental mercury, which is also collected on silver wool. This method provides data on both elemental and total mercury (Spittler, 1976). The analytical method now generally used is based on revolatilization of the collected mercury sample and passage through a gas optical cell in a flameless atomic absorption spectrometer.

Soldano et al. (1974, 1975) described the results of a survey of airborne mercury concentrations in the environs of sewage treatment plants, using an adaptation of mercury speciation technique described by Braman et al. (1974). This technique involves the stacking of four different materials to collect different forms of mercury:

Acid Chromosorb W - Inorganic mercury compounds
Basic Chromosorb W - Alkyl mercury halides
Silvered sand - Elemental mercury
Gold-coated sand - Dialkyl forms of mercury

Results were presented for a number of cities (Table 2.1). Large differences in mercury concentration were found among the different cities and among samples obtained within the same city. The results range from a low of 0.13 ng/m^3 in a Utica, New York, sample to 600,000 ng/m^3 in a Memphis, Tennessee, sample. Factors such as weather conditions, distance from the sewage plant, and elevation of the collection point are cited as factors influencing the results within a city. All forms of mercury were found;

TABLE 2.1. A COMPARISON OF MERCURY CONCENTRATIONS IN THE AIR AS A FUNCTION OF SPECIES AND LOCATION

Sample Location[a]	Set No.	Concentration, ng/m^3			
		Acidic (Inorganic Mercury)[b]	Basic (Alkyl Mercury Halides)[b]	Silver (Elemental Mercury)[b]	Gold (Dialkyl Forms)[b]
Richmond (I)	2	20	--	2.50	--
Richmond (I)	4	2.13	62.50	--	--
Richmond (II)	1	0.25	8,750	1.60	--
Richmond (II)	2	0.88	0.53	1.80	--
Richmond (II)	3	0.78	0.50	0.80	--
Richmond (II)	4	1.25	9.50	6.80	--
Richmond (II)	5	2.50	0.85	1.80	0.50
TVA (Bull Run)	1	0.43	0.83	0.53	0.33
Oak Ridge TN	1	1.98	1.38	1.58	2.75
Knoxville TN	1	3.75	107.50	1.75	4
Knoxville TN	2	1.30	21.75	0.35	0.55
Memphis TN	1	210	2,262	380	285
Memphis TN	2	1,428	9,525	42,800	4,750
Memphis TN	23	2,930	1,050	1,360	3,330
Memphis TN	24	2,090	4,180	23,300	13,950
Memphis TN	25	1,667	3,800	3,330	1,380
Memphis TN	26	1,237	7,625	16.7	285
Memphis TN	27	2,875	33,250	5,500	3,700
Memphis TN	28	4,225	2,625	10,000	4,530
Memphis TN	29	140	130	240	210
Memphis TN	30	3,250	3,730	932	605
Memphis TN	32	186	383	488	465
Memphis TN	33	275	198	1,333	4,780
Memphis TN	36	3,280	8,580	17,100	515
Memphis TN	37	15,875	1,032	15,950	6,975
Memphis TN	38	3,750	6,250	600,000	10,000
Memphis TN	39	3,800	19,000	1,357	452
Greenville SC	1	0.12	0.68	0.08	1.50
Greenville SC	2	7.75[c]	--	--	--
Greenville SC	2	1.23	--	21.25	1.55
Greenville SC	3	11.25	67.50	0.58	3.50
Greenville SC	4	0.30	6.50	225	25
Utica NY	2	--	0.13	--	--
Utica NY	4	0.15	3.25	0.20	3.50
Utica NY	5	0.36	0.80	0.60	--
Utica NY	6	0.21	0.95	0.33	1.68
Louisville KY	13	410	308	718	410
Louisville KY	14	1,470	2,950	1,410	15,300
Louisville KY	15	2,093	9,300	1,395	465
Louisville KY	16	1,105	13,159	2,625	1,262
Louisville KY	19	6,250	42,500	550	2,375

Source: Soldano et al. (1974, 1975).

[a] All are in the environs of sewage treatment plants except TVA which is a coal-fired steam plant.

[b] Positive identifications of the mercury forms were not made but were inferred from the collected fractions.

[c] Interference.

and the authors indicate that the mercury concentration-distance dependency varies with the mercury form, a less volatile form (elemental mercury) declining in concentration with increasing distance from the plant, and the form collected in the basic fraction (highly volatile alkyl mercury halides) increasing in concentration with increasing distance. The results are compared with the lower concentrations obtained near a TVA coal-fired steam plant at Bull Run, and the conclusion is drawn that the results provide evidence for mercury and organic mercury pollution of the air that can be attributed to municipal sewage treatment facilities. The sewage treatment facilities may constitute a means of concentrating elemental mercury and reemitting it, in combination with the organic products characteristic of sewage systems, into the air (Soldano et al., 1975). The authors correlate their maximum observed organic mercury concentrations with the population load on the sewage facility, Oak Ridge and Utica being the smallest and Memphis the largest.

The largest variety and number of recent analyses are those generated by Spittler (1976). In the first set of analyses of locations in North Carolina sampled in 1972, the double-air-stream instrument was used, permitting analysis for both elemental and total mercury. Results for three cities are shown in Table 2.2. The total mercury concentrations in the three cities ranged from 4 to 8 ng/m^3.

TABLE 2.2. ELEMENTAL AND TOTAL ATMOSPHERIC MERCURY CONCENTRATIONS IN THREE NORTH CAROLINA CITIES

Date 1972	Location	Concentration, ng/m^3 Total	Elemental	Total Minus Elemental
October 3	Cary NC	6.0	6.0	0.0
4		6.9	6.8	0.1
5		8.1	6.1	2.0
6-8		7.7	5.7	2.0
October 3	Durham NC	3.8	4.7	-0.9
4		4.3	4.4	-0.1
5		6.9	4.8	2.1
6-7		5.3	3.5	1.8
October 3	Raleigh NC	5.7	6.0	-0.3
4		6.4	6.8	-0.4
5		5.9	5.8	0.1
6-9		4.2	4.1	0.1

Source: Spittler, 1976.

In Spittler's opinion, most airborne mercury will be found to be in the elemental form unless some very special problem is known to exist or a specific industrial source is under investigation. In conformance with this conclusion (which appears to be in harmony with the data in Table 2.2), only elemental mercury was measured in subsequent analyses conducted in 1975 and 1976.

During 1975 and 1976 mercury analyses were conducted on a variety of samples mostly from Massachusetts, Connecticut, Rhode Island, Vermont, and Maine, with a scattering of other samples from Indiana, Ohio, Illinois, and Florida. Results of these analyses are presented in Table 2.3. Over 90 percent of the samples yielded mercury concentrations in the range of 2 to 60 ng/m^3, the ambient urban air concentration reported by Goldwater (1971) and Cooper et al. (1974). The most significant exceptions were a level of 5,820 ng/m^3 in a power plant plume in Fall River, Massachusetts, a level of 275 ng/m^3 in the plume from a burning dump in Middleton, Massachusetts, and 200 ng/m^3 in an incinerator plume in Marlboro, Massachusetts. Several samples were obtained in airports, but they did not yield results any higher than ambient levels.

A number of urban atmospheres were sampled by Cooper et al. (1974) using a gold-screen collector. Results are summarized in Table 2.4. The two highest concentrations, El Paso, Texas, and Kellogg, Idaho, were from samples taken near nonferrous smelting operations. Other samples ranged between 5.0 and 14.4 ng/m^3. In this same study, automobile exhaust gases were sampled and found to contain between 95 and 160 ng/m^3; the fuel was not analyzed. These data suggest that transportation sources may be significant sources of mercury emission due to the mercury content of petroleum. This conclusion is supported by near-highway measurements by Cooper et al., which showed mercury concentrations from ca. 5 ng/m^3 during low-traffic hours to 10 to 12 ng/m^3 during peak traffic hours.

A series of duplicate samples taken during 1973 in Chicago (Wroblewski et al., 1974) at nine sites, using a silver-wool collector, showed average mercury concentrations to range from 10 to 38 ng/m^3; the average for all sites was 22 ng/m^3. Individual samples ranged from 5 to 60 ng/m^3, and in most instances, duplicate samples agreed within 20 percent.

In contrast to the above values, monthly composites of Hi-Vol filter samples collected during September-November, 1971, averaged only from 3.8 to 4.1 ng/m^3. These data were considered to be evidence that either only a portion of the mercury was associated with particulates or losses were occurring during the collection of Hi-Vol samples.

Jepsen (1973) reported a series of measurements of atmospheric mercury concentrations in California, a state with a large fraction of the U.S. deposits or mercury ores, as well as a large portion of U.S. geothermal steam fields. He used a portable Barringer airborne mercury spectrometer (BAMS) and sampled by bus, car, helicopter, and boat, utilizing traverses to locate, quantify, and map anomalous mercury plumes. Several previously unreported sites of mercury contamination associated with natural sources, such as mercury mines and hot springs areas, and cultural sources such as

TABLE 2.3. SUMMARY OF ATMOSPHERIC MERCURY MEASUREMENTS AT SELECTED U.S. LOCATIONS

Location	Date	Time	Concentration,[a] ng/m^3
Connecticut			
Groton	Aug. 5, 1975		49
Hamben	Aug. 7, 1975		107
Hartford	April 11, 1976		20
Suburbs			13
Middleton	Aug. 7, 1975		29
New Haven			14
Georgia			
Atlanta, airport	Nov. 10, 1975		3.5
Illinois			
Chicago	Oct. 4, 1975		7.0
Wheaton	Oct. 3, 1975		1.9 (2.4)
Indiana			
Indianapolis	Oct. 5, 1975		4.4 (4.9)
	Oct. 6, 1975		17.7 (19.4)
			5.4 (8.4)
Indianapolis, airport	Oct. 7, 1975		33.2
Maine			
Allagash River Basin	Sept. 8, 1975		33
			4.6
			8
			36
			43
	Nov. 3, 1975		12
			20
			8
			16
			15
			4.3
			11
			9
	Dec. 16, 1975		3
			30
			39
			8
			13
			11
			8.6
			12

TABLE 2.3. (Continued)

Location	Date	Time	Concentration,[a] ng/m^3
Massachusetts			
Boston	Feb. 27, 1976		12
Airport, inside	Nov. 10, 1975		13
JFK parking lot	Dec. 10, 1975		20
Over harbor, in plane	Aug. 15, 1975	0700-1000	9 (14)
Ditto	Ditto	1000-1200	5.4 (7.3)
Fall River, in power plant plume			5820
Framingham	Dec. 9, 1975		5.5
In incinerator plume	Aug. 8, 1975		42
Lexington	May 10, 1976		9.8 (10.3)
Marlboro	Aug. 5, 1975		16 (20)
			17 (13)
			3.6 (3.8)
			20.7
			7.1 (8.6)
			22.5
			19.2
			4 (6)
			3 (4)
			11 (12)
Incinerator, across street	April 11, 1976		88
Incinerator, in plume	Ditto		200
Incinerator, 320 m downwind	"		26
Middleton			
In plume from burning dump	Nov. 28, 1975		275
90 m downwind of dump	Ditto		45
1.6 km downwind of dump	"		25
3.2 km downwind of dump	"		12.5
8.0 km downwind of dump	"		10
Milton	Aug. 21, 1975	1530-1730	25
	Aug. 22, 1975	0800-1000	16.5
	Ditto	1000-1200	14.6
	Aug. 26, 1975	0900-1200	13.5
	Ditto	1200-1500	5.2
	Aug. 27, 1975	0800-1100	8.0
	Ditto	1100-1500	7.5
	Aug. 28, 1975	0800-1200	53
Needham	Aug. 6, 1975		9.6 (10.6)
	Sept. 3, 1975		4 (4)
Norwood, airport	Nov. 28, 1975		15
Walpole	Aug. 6, 1975		10 (7.5)

TABLE 2.3. (Continued)

Location	Date	Time	Concentration,[a] ng/m^3
Ohio			
Cleveland, airport	Oct. 7, 1975		6.9
Dayton, airport			18.7
Parma			4.9
Rhode Island			
Providence	Aug. 5, 1975		105
Vermont			
Burlington	Aug. 13, 1975		62 (55)
Rutland	Oct. 16, 1975	1400-1500	7.5
	Ditto	1600-1700	17
	"	2000-2300	3.3
	Oct. 17, 1975	0930-1200	20

Source: Spittler, 1976.

[a] Values in parentheses are replicates.

TABLE 2.4. AMBIENT OUTDOOR MERCURY CONCENTRATIONS IN SELECTED U.S. CITIES

City	Time of Sample Collection	Concentration, ng Hg/m^3 air	Sample Location
El Paso TX	0945	29.6	Industrial
Kellogg ID	1530	21.5	Industrial
Oakland CA	1140	14.4	Freeway
Chicago IL	1320	13.0	Hospital
Memphis TN	1040	11.8	Industrial
Berkely CA	1040	10.5	Commercial
San Francisco CA	1745	10.3	Freeway
Tucson AZ	1710	9.5	Freeway
Seattle WA	1805	8.6	Residential
Louisville KY	1335	5.9	Commercial
Nashville TN	1655	5.0	Freeway

Source: Cooper et al., 1974.

chlor-alkali and other chemical plants, sewage treatment plants, and sanitary landfills were identified. By far the largest mercury concentration was detected in a steam vent at the Geysers, as shown by Table 2.5, which highlights the anomalies from the reconnaissance program, which covered over 30,000 km^2. Other natural sources with higher-than-average concentrations were near the New Almaden mercury mine, as well as in the Clear Lake area, near the still-active Abbott mine, and the closed Sulfur Bank mine. However, most of the measurements were at normal ambient levels, in the range from 0 to 10 or 15 ng/m^3, comparable to levels in other states.

Measurements of mercury scrubbed from the air by rainfall have been made by several investigators. In one of the most recent studies, Schlesinger et al. (1974) measured mercury and lead deposited by rainfall in an isolated area on the western slope of a New Hampshire mountain at elevations ranging from 486 to 1,372 m (1,590 to 4,500 ft). During the period June 30 to November 7, 1971, the collected precipitation averaged 0.06 ppb mercury, and the mean deposition was calculated to be 0.23 ng/m^2 day.

WATER AND SEDIMENTS

National Monitoring Program

Data on mercury in water are reported for two forms: dissolved and total. Dissolved mercury is determined on filtered (0.45 micron membrane) samples, and provides an indication of what might occur in a treated or

TABLE 2.5. SUMMARY OF CALIFORNIA ATMOSPHERIC MERCURY MEASUREMENTS

Site	Date[a]	Time	Wind	Mercury Background Level, ng/m^3	Mercury Peak Value, ng/m^3	Comments
Natural Sources						
Abbott Mine	Feb. 12	P.M.	E	0	470	Low population density
Clear Lake	Feb. 12	P.M.	E	0	150	Resort area, low population density
	April 2	P.M.	W	0	200	
The Geysers	Feb. 15	P.M.	W	200-800	28,100	Rural resort area
New Almaden	Jan. 4	P.M.		0	1,500	Rural
	March 24	P.M.		5-15	449	
Cultural Sources						
Berkeley	March 22	A.M.	W	10	800	Light industrial-residential
	March 24	A.M.	W		449	
	March 26	P.M.	W	10	154	
	March 30	P.M.	W	0	1,050	Downwind of landfill
Oakland-Emeryville	March 30	P.M.	NW	0	196	Light industrial
	April 5	P.M.	W	0	668	Industrial complex
	April 6	P.M.	W	0	110	Downwind of STP flare
					700	Industrial area
Pittsburgh	Feb. 11	P.M.	E	50	1,000	Industrial area
	Feb. 12	A.M.	NW	0	0	On boat
	Feb. 25	A.M.	N	0	10	Residential
	March 22	P.M.	WNW	5	4,141	Industrial-residential
	April 1	A.M.-P.M.	N	0		
San Francisco	March 18	P.M.		0	278	Commercial area, quicksilver products
	March 19	A.M.		0	152	
	Jan. 19-26	A.M.-P.M.		0	100	Ambient measurements, financial district
	April 7,8	A.M.-P.M.		0	35	
Richmond	March 29	A.M.	NW	5	1,400	Residential, near primary school
		P.M.	W	5	2,000	

Source: Jepsen, 1973.

[a] Date not given, probably 1971.

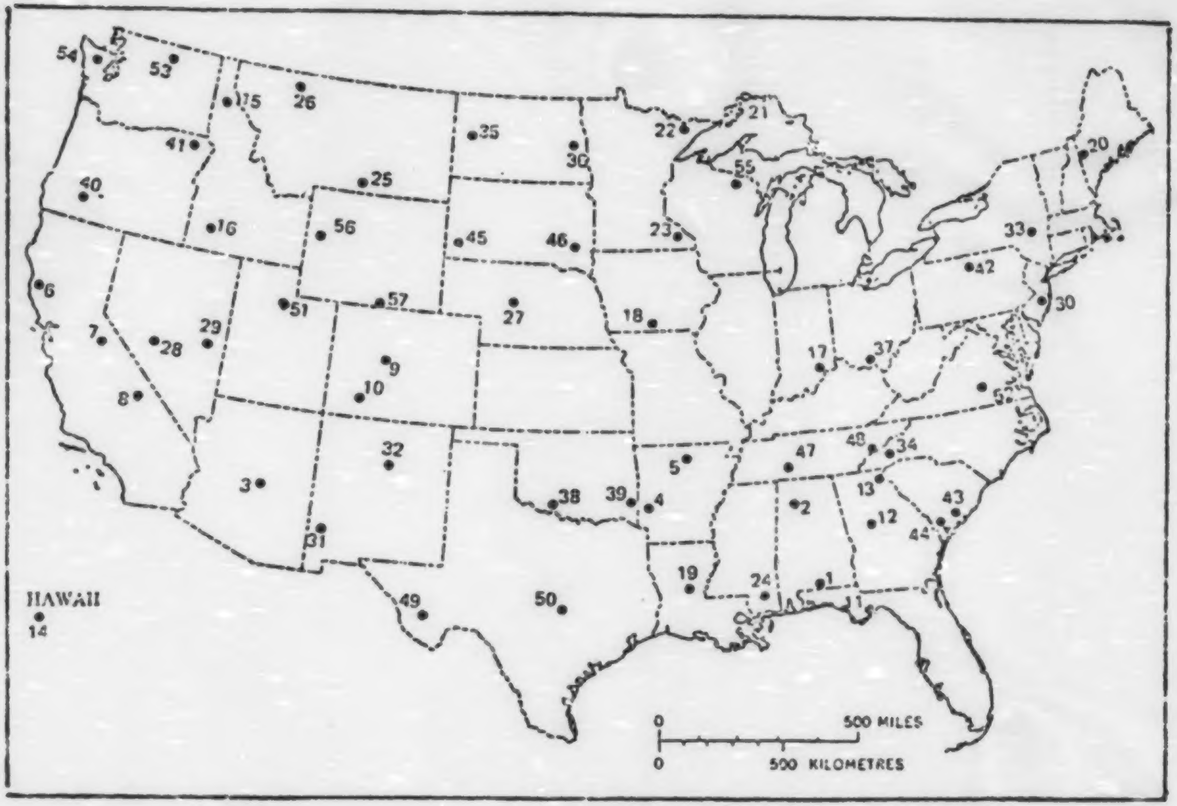
filtered water supply drawn from the same source. Total mercury represents the amount in the water-sediment mixture, and is indicative of what might be included in the food chain of the aquatic community (Durum et al., 1971). Most of the analyses contained in this report are of total mercury.

A nationwide reconnaissance of selected minor elements in the surface waters of the 50 states and Puerto Rico was conducted by the U.S. Geological Survey in cooperation with the U.S. Bureau of Sport Fisheries and Wildlife in the autumn of 1970 (Durum et al., 1971). There were three kinds of samples:

- Benchmark stations
- Surface water sources for cities greater than 100,000 population (or largest city in state)
- Water courses downstream of major municipal and/or industrial complexes.

The presence of mercury was reported in 19 percent of the 722 published analyses (Durum, 1974). Dissolved mercury was detected (greater than 1 ppb) in about 7 percent of the samples. In 21 samples mercury was found in both the unfiltered sample (0.5 ppb detection limit) and the filtered (0.1 ppb detection limit) companion sample. In about half of the waters in which mercury was detected, a significant fraction of the mercury was being transported in the particulate fraction (Durum, 1974). The "benchmark" stations were established by the Geological Survey in the mid-1950's for purposes of measuring long-term natural trends in stream flow and water quality. Benchmark stations are located toward the headwaters of tributary streams in these basins, in generally undeveloped areas, and thus are presumably fairly free from contamination. Their locations are shown in Figure 2.2. Examination of the mercury analyses from the 49 benchmark stations included in the summary of the reconnaissance (Durum et al., 1971) showed that mercury was undetected in 43 (88 percent). California and Nevada are two of the principal areas of mercury mineralization, and it was not surprising that mercury was detected at two benchmark stations in each state (0.8 to 6.0 ppb). Except for these, mercury was detected only at single benchmark stations in Maine (0.6 ppb) and in Hawaii (1.2 ppb).

The Geological Survey, in an unpublished report submitted to the U.S. House of Representatives, Committee on Merchant Marine and Fisheries (Pickering, 1976), summarized the data in its computer storage file (accessed up to mid-January, 1976) on six toxic substances, including mercury. These data are also presumed to include the results of the 1970 reconnaissance. The data for mercury in surface waters (streams, lakes, and reservoirs) and in groundwaters (wells and springs) have been extracted from this summary and are presented in Tables 2.6 and 2.7, and summarized in Table 2.8.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500 KILOMETRES

Figure 2.2. Location of hydrologic benchmark stations maintained by the U.S. Geological Survey.

TABLE 2.6. MERCURY LEVELS IN SURFACE WATERS OF THE UNITED STATES

State	Dissolved Mercury[a]				Total Mercury[b]				Mercury in Bottom Material		
	N[c]	N>0[d]	N>2, ppb	Max,[e] ppb	N[c]	N>0[d]	N>0.2, ppb	Max,[e] ppb	N[c]	N>0[d]	Max,[e] ppm
Alabama	94	88	24	56	47	39	35	0.7	3	4	1.7
Alaska	21	9	1	4.0	42	34	25	2.2	0		
Arizona	23	17	0	0.6	13	12	0	32	1	0	0.0
Arkansas	32	28	6	4.3	100	81	72	15	13	13	0.5
California	99	75	16	12	157	99	80	12	26	22	0.3
Colorado	362	196	3	4.5	122	44	16	1.8	48	47	0.1
Connecticut	34	34	1	3.8	30	30	30	0.7	38	36	3.7
Delaware	0				0				0		
Florida	50	40	1	3.6	296	230	193	22	83	69	4.0
Georgia	77	42	3	2.0	40	6	4	1.8	11	8	0.6
Hawaii	14	12	0	1.2	10	8	3	0.9	3	3	0.1
Idaho	66	60	11	8.7	43	43	40	8.3	1	0	0.0
Illinois	82	79	1	2.2	26	24	23	3.5	6	5	0.1
Indiana	27	20	0	0.8	23	17	11	0.8	6	0	0.0
Iowa	9	9	4	24	15	15	12	1.8	0		
Kansas	20	14	3	3.0	29	29	26	10	1	0	0.0
Kentucky	96	78	4	7.5	95	87	78	7.9	39	32	15
Louisiana	190	122	2	2.3	155	133	121	5.0	188	170	9.0
Maine	11	11	0	0.6	16	16	16	5.5	5	3	0.1
Maryland	2	2	1	5.0	2	2	2	5.0	1	0	0.0
Massachusetts	18	18	2	4.7	21	21	21	0.7	0		
Michigan	103	91	16	196	79	73	61	240	1	1	1.7
Minnesota	30	22	1	2.6	41	30	21	10	21	21	0.2
Mississippi	20	16	2	2.7	67	56	30	17	53	31	37
Missouri	14	8	1	4.3	28	21	16	4.8	2	0	0.0
Montana	84	72	7	9.0	82	66	56	11	5	5	0.2
Nebraska	63	56	17	44	66	60	53	92	0		
Nevada	8	8	0	1.8	15	13	12	25	0		
New Hampshire	6	6	1	3.7	22	22	22	0.7	0		
New Jersey	32	32	1	2.8	53	42	41	5.9	10	8	270
New Mexico	23	14	0	0.5	77	51	32	4.0	1	0	0.0

TABLE 2.6. (Continued)

State	Dissolved Mercury[a]				Total Mercury[b]				Mercury in Bottom Material		
	N[c]	N>0[d]	N>2, ppb	Max,[e] ppb	N[e]	N>0[d]	N>0.2, ppb	Max,[e] ppb	N[c]	N>0[d]	Max,[e] ppm
New York	74	74	2	17	360	360	360	2,800	6	6	0.3
North Carolina	34	28	0	0.8	76	51	48	8.8	18	17	0.6
North Dakota	72	58	11	76	70	46	34	3.3	3	0	0.0
Ohio	31	31	1	6.0	353	353	351	61	1	0	0.0
Oklahoma	20	12	3	12	27	24	18	15	6	6	0.1
Oregon	19	14	0	1.0	13	11	7	2.5	4	0	0.0
Pennsylvania	61	61	0	1.3	184	181	172	50	35	33	70
Rhode Island	9	9	0	0.5	9	9	9	0.5	0	0	
South Carolina	11	10	0	0.3	11	11	11	0.5	5	4	0.5
South Dakota	23	14	0	1.0	39	26	19	1.7	0	0	
Tennessee	19	18	0	0.6	58	53	35	110	1	0	0.0
Texas	157	142	37	160	33	30	24	1.6	3	1	0.2
Utah	78	50	2	7.0	37	20	12	1.3	0	0	
Vermont	4	4	1	3.4	4	4	4	0.5	0	0	
Virginia	4	4	0	1.6	4	4	4	0.6	0	0	
Washington	11	10	1	2.1	160	142	121	2,700	1	0	0.0
West Virginia	52	52	3	5.0	50	50	50	5.0	15	7	0.1
Wisconsin	36	25	1	2.0	30	20	10	1.2	13	7	3.0
Wyoming	60	23	2	2.4	66	31	22	2.1	3	0	0.0
United States	2,515	1,918	193	196	3,396	2,830	2,472	2,800	650	559	270

Source: Pickering, 1976.

[a] Filtered sample.

[b] Unfiltered sample.

[c] N = Number of stations for which data are available.

[d] N>0 = Number of stations with detectable mercury.

[e] Max = Maximum value found.

TABLE 2.7. MERCURY LEVELS IN GROUNDWATER OF THE UNITED STATES

State	Dissolved Mercury[a]				Total Mercury[b]			
	N[c]	N>0[d]	N>2, ppb	Max,[e] ppb	N[c]	N>0[d]	N>0.2, ppb	Max,[e] ppb
Alabama	54	48	5	10	0			
Alaska	21	7	0	0.6	18	12	6	1.7
Arizona	22	11	0	0.2	0			
Arkansas	20	7	0	0.4	0			
California	62	21	0	1.0	34	26	18	20
Colorado	305	77	5	5.3	9	2	1	0.2
Connecticut	10	8	1	5.0	6	6	6	0.5
Florida	92	68	0	1.7	302	219	148	4.0
Georgia	191	92	2	5.6	0			
Idaho	138	77	3	4.3	0			
Indiana	51	34	6	9.8	0			
Iowa	6	6	0	1.0	0			
Kentucky	7	6	0	1.4	5	2	1	0.2
Louisiana	1	1	0	1.4	22	16	11	0.5
Michigan	7	6	1	13	23	13	8	1.1
Minnesota	0				11	2	1	0.6
Mississippi	3	0	0	0.0	4	0	0	0.0
Missouri	0				16	9	8	2.2
Montana	40	20	1	2.0	0			
Nebraska	151	67	6	13	0			
New Hampshire	0				16	16	15	5.0
New Jersey	7	6	0	0.5	31	31	31	7.1
New Mexico	10	7	0	0.7	88	21	8	2.2
New York	17	17	0	1.0	209	209	209	31
North Carolina	1	0	0	0.0	6	6	5	14
North Dakota	78	45	2	2.4	11	9	3	0.6
Ohio	0				5	5	5	0.5
Oklahoma	9	1	0	0.1	0			
Oregon	1	0	0	0.0	12	1	1	0.4
Pennsylvania	63	63	1	11	7	5	5	0.9
South Dakota	0				56	17	13	0.5
Tennessee	0				18	13	5	0.2
Texas	74	53	0	1.9	0			
Utah	57	29	0	1.0	0			
Virginia	2	2	0	0.2	0			
Washington	0				39	31	4	0.7
West Virginia	19	19	0	0.5	19	19	19	5.9
Wisconsin	32	22	0	0.9	0			
Wyoming	52	17	1	2.1	54	25	13	5.3
United States	1,603	837	34	13	1,021	715	544	31

Source: Pickering, 1976.

[a] Filtered sample.

[b] Unfiltered sample.

[c] N = Number of stations for which data are available.

[d] N>0 = Number of stations with detectable mercury.

[e] Max = Maximum value found.

TABLE 2.8. SUMMARY OF MERCURY CONCENTRATIONS IN U.S. WATERS

	Surface Waters		Groundwater	
	Dissolved	Total	Dissolved	Total
Number of states sampled	49	49	32	25
Number of sites sampled	2,515	3,396	1,603	1,021
Positive values				
Number	1,918	2,830	837	715
Percent	76.3	69.3	52.2	70.0
Values >2 ppb				
Number	193		34	
Percent	7.7		2.1	
Values >0.2 ppb				
Number		2,472		544
Percent		72.8		53.3
Maximum value, ppb	196	2,800	13	31

Dissolved values shown are based on the analyses of water passed through a 0.45 micrometer filter; "total" values are for unfiltered samples containing suspended sediment. Dissolved values are compared with the 2 ppb maximum mercury level contained in the National Interim Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 1975a). For "total" values the comparison is with the 0.2 ppb criterion recommended in Water Quality Criteria 1972 for freshwater aquatic life and wildlife (Rooney, 1973). In only 2 to 8 percent of the samples did dissolved mercury exceed the 2 ppb limit recommended for drinking water, but in 53 to 73 percent the total mercury exceeded the more stringent 0.2 ppb water quality criterion recommended for mercury by the National Academy of Sciences. The Geological Survey data indicate that on the average, groundwater quality with respect to mercury exceeds that of surface water.

Data from a separate nationwide study of mercury in waters has been summarized by Jenne (1972). A majority of the samples analyzed contained less than 0.5 ppb. About 17 percent had mercury contents of 1 ppb or greater. Only 4 percent of the surface water samples contained in excess of 10 ppb mercury. The higher mercury concentrations were generally found in small streams. About half of the 43 samples from the Mississippi River contained less than 0.1 ppb. The mercury content of lakes and reservoirs was scattered between less than 0.1 and 1.8 ppb. With few exceptions, the mercury content of qroundwater samples was below the limit of detection.

In summarizing the present status of U.S. waters, Durum (1974) stated that on the basis of the surveys to date in which the preponderance of analyses show mercury to be below the limit of detection, the natural background level of total mercury in surface and underground water is certainly below 0.5 ppb, and is probably considerably lower than that.

Confirmation of this conclusion is provided by the EPA STORET data for 1970-1974 presented in the 6th Annual Report on Environmental Quality (Council on Environmental Quality, 1976) shown in Figure 2.3. The range of mercury concentrations in surface waters is from 0.04 to 0.10 ppb.

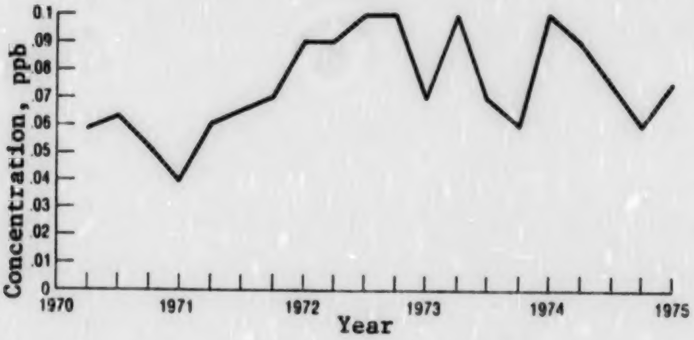

Figure 2.3. Mercury levels in U.S. surface waters, 1970-1974 (Council on Environmental Quality, 1976).

Local Monitoring of Mercury Concentrations

Local studies of mercury concentrations in water and sediments have been conducted in recent years in most of the major U.S. drainage basins (see Figure 2.4). Many of these studies were conducted to investigate an identified or suspected mercury-enrichment problem, so that averaging the findings of the various studies can be misleading with respect to defining average ambient concentrations. Selected localized investigations are briefly summarized in the following paragraphs.

The North Atlantic Basin(1)* is in one of the most highly urbanized and industrialized regions of the country, and high mercury concentrations in water, and particularly in sediments, are possible. Illustrative are the sediment mercury concentrations determined in Baltimore Harbor by Villa

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*Numbers in parentheses refer to drainage basins identified in Figure 2.4.

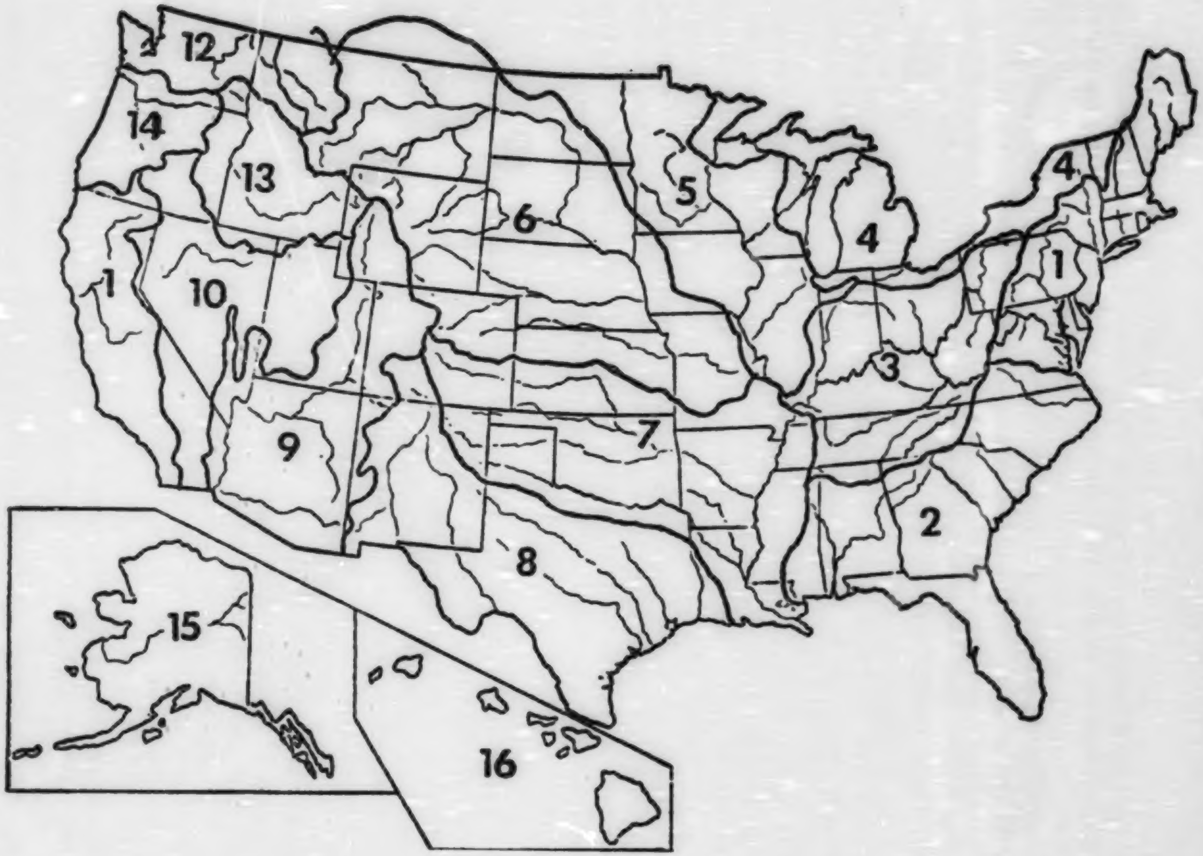
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Figure 2.4. U.S. Geological Survey classification of major drainage basins in the United States.

and Johnson (1974), as shown in Figure 2.5. The distribution of mercury was found to correlate with large industrial complexes, and concentrations of up to 6 ppm were observed. The heaviest concentrations can be seen to be located in the more sheltered areas away from the main channel and in the areas of manufacturing industry or marine and commercial establishments.

Roberts et al. (1975) has compiled state data for mercury. Sediment samples from Boston Harbor were found to have mean concentrations of 2 to 3 ppm of mercury; sediment levels were generally higher at the sediment surface, and the highest mercury levels correlated with high organic content. In other Massachusetts sediment samples at Taunton River and Muddy Cove, means were 2 to 36 ppm, with a range of 0.1 to 130 ppm. Unlike the usual study in which there is no breakdown of the form of the mercury, this study also determined methylmercury content and found that only a very small fraction, 0.1 to 0.5 percent, was in the methylmercury form.

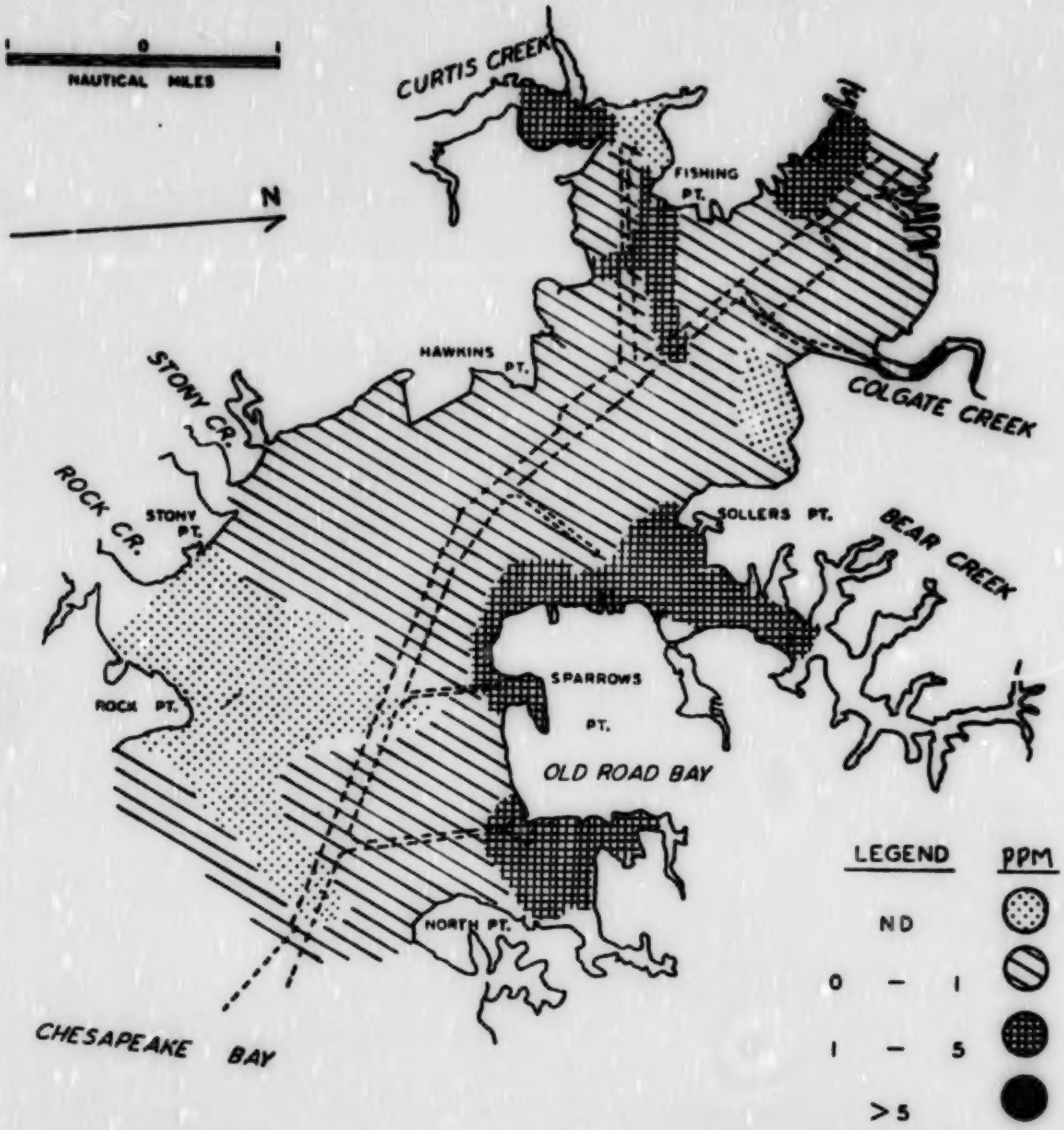
Similarly, low fractions of methylmercury, only 0.03 to 0.07 percent of total mercury, were found in the Everglades (Andren and Harris, 1973).

The Ohio River Basin(3) is one of the major U.S. drainage basins, especially whth respect to the population served, and to the industrial concentration within it. The Ohio River Valley Water Sanitation Commission (ORSANCO) has monitored the Ohio River and its major tributaries for some years, now including some of the heavy metals. Recent (1975-1976) mercury results (Table 2.9) are illustrative of present levels in the Ohio River as it passes through an industrialized area. Most of the samples are below the limit of detection and the median value is certainly below 0.5 ppb; only one value exceeds 1 ppb.

The St. Lawrence River Basin(4) includes the Great Lakes, in which mercury concentrations have been studied extensively since about 1969, when mercury contamination was discovered in fish taken in Canadian waters of Lake St. Clair. Most of the mercury contamination was ascribed to discharges from chlor-alkali plants; controls have since been instituted which have essentially eliminated such discharges.

Chau and Saitoh (1973), in summarizing the results of a 2-year survey of mercury concentrations in international Great Lakes waters, concluded that the distribution of mercury is quite uniform; the mercury levels in the majority (75 percent) of the samples fell within the 0 to 0.4 ppb range for all lakes. The mean concentrations for 915 water samples (surface, intermediate, and bottom) from Lakes Ontario, Erie, Huron, and Superior, were 0.13, 0.17, 0.17, and 0.18 ppb, respectively. Chau and Saitoh classified the average mercury concentrations as low compared with those for the lakes and reservoirs of the United States considered by Jenne (1972).

Chay and Saitoh also concluded on the basis of a comparison of their work with others that there is no direct relationship between mercury distributions in the water and sediments of the Great Lakes. The sediment mercury concentrations, as a nonmobile phase, reflect closely the areas of industrial inputs, whereas water does not. Confirmation of the correlation of sediment concentrations and industrial inputs can be found in the study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HAWKINS PT.
COLGATE CREEK
STONY CR.
ROCK CR.
STONY PT.
SOLLERS PT.
BEAR CREEK
ROCK PT.
SPARROWS PT.
OLD ROAD BAY
NORTH PT.
CHESAPEAKE BAY
LEGEND
PPM
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0 – 1
1 – 5
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Figure 2.5. Mercury levels in Baltimore Harbor sediments.

TABLE 2.9. MERCURY CONCENTRATIONS IN THE OHIO RIVER AND SOME OF ITS TRIBUTARIES

Location	Date of Data Collection	Number of Samples	Frequency of Detection, %	Range of Mercury Concentration, ppb
Illinois				
Ohio River at Joppa	Oct. 1975-April 1976	6	50	0.0-0.3
Indiana				
Ohio River at Evansville	Nov. 1975-April 1976	6	50	0.0-0.1
Ohio River at Uniontown	" "	6	67	0.0-0.1
Kentucky				
Licking River, Kenton County	" "	7	0	<0.5
Ohio River at Louisville	Oct. 1975-April 1976	7	57	0.0-0.2
Ohio River at West Point	Nov. 1975-April 1976	6	33	0.0-0.1
Green River at Sebree	Oct. 1975-April 1976	6	33	<0.5
Ohio				
Ohio River at East Liverpool	Sept. 1975-April 1976	8	13	<0.5-0.5
Ohio River at Shadyside	" "	8	0	<0.5
Muskingum River at Marietta	" "	8	0	<0.5
Ohio River at Belleville	" "	7	0	<0.5
Ohio River at Kyger Creek	Oct. 1975-April 1976	7	0	<0.5
Ohio River at Kenoga	Nov. 1975-April 1976	6	0	<0.5
Scioto River at Lucasville	Oct. 1975-April 1976	7	0	<0.5
Ohio River at Meldahl	" "	7	0	<0.5
Ohio River at Cincinnati	" "	7	0	<0.5
Little Miami River	Sept. 1975-April 1976	8	13	<0.5-1.2
Greater Miami River	Oct. 1975-April 1976	6	0	<0.5
Pennsylvania				
Allegheny River at Oakmont	Sept. 1975-April 1976	7	15	<0.5-0.5
Monongahela River at St. Pittsburgh	" "	7	14	<0.5-0.5
Ohio River at South Heights	" "	8	13	<0.5-0.5
Beaver River at Beaver Falls	" "	8	13	<0.5-0.5
West Virginia				
Ohio River at Pike Island	" "	8	13	<0.5-0.5
Ohio River at Willow Island	" "	8	0	<0.5

Source: Ohio River Valley Water Sanitation Commission, 1975, 1976.

of mercury contents of sediment cores from western Lake Erie by Kovacik and Waters (1973). They determined that the mercury concentrations in sediments related directly to the flow pattern of Detroit River water into the lake, carrying mercury from chlor-alkali plants upstream. They found also that modern sediments exhibited a surface enrichment zone of 1 to 4 ppm which decreased exponentially with depth to the background level of 0.04 to 0.08 ppm observed below about 15 cm in most cores. Their data indicated that no change has occurred in background levels until modern times.

Results of an unpublished EPA study (U.S. Environmental Protection Agency, 1976a) provide additional data on the mercury contents observed in 403 sediment samples collected from harbors along the shores of the Great Lakes between Erie, Pennsylvania, and Duluth, Minnesota. As shown in the frequency distribution curve in Figure 2.6, over 98 percent of the samples were below 0.7 ppm, and approximately 85 percent contained 0.2 ppm or less. Approximately 60 percent were below the detection limit of 0.1 ppm. Only three samples, all from the Great Lakes Naval Training Base, Illinois, exceeded 0.7 ppm (2.0, 3.0, and 14.0 ppm).

Localized investigations in other basins provided similar patterns of mercury distribution. The highest levels of mercury in surface waters tended to be associated with periods of low flow, implying the effect of a dilution factor during periods of high flow. Elevated concentrations in sediments appeared to be related to inputs from nearby point sources. Sediment mercury concentrations showed positive correlations with organic content, small particle size, and sulfur content. Undisturbed sediment cores generally exhibit a decreasing mercury content with depth. Although methylmercury analyses are few in number, the evidence is consistent that the fraction of total mercury present in sediments in this form is very low.

DRINKING WATER

The U.S. Public Health Service conducted one of the first broad-based investigations of drinking water quality in 1969. The study was designed to give an assessment of drinking water quality in urban and suburban areas, and it may be considered to comprise the baseline against which current concentrations of toxic substances can be compared. However, mercury was not measured in this survey but was covered in a separate study conducted in 1970-1971 by the Environmental Protection Agency. Results of this survey, as summarized by Hammerstrom et al. (1972), disclose that 261 (96 percent) of the 273 communities sampled had less than 1 ppb of mercury; 11 (4 percent) were between 1 and 5 ppb; and one exceeded the 5 ppb level.

The above indication of a mercury level above 5 ppb led to an extensive follow-up sampling program in which 192 raw and finished water samples were collected at four plants in this system over a 3-week period. The mercury concentration was found to be less than 0.25 ppb in 153 samples, and less than 0.8 ppm in the remaining 30, casting some doubt upon the original analyses.

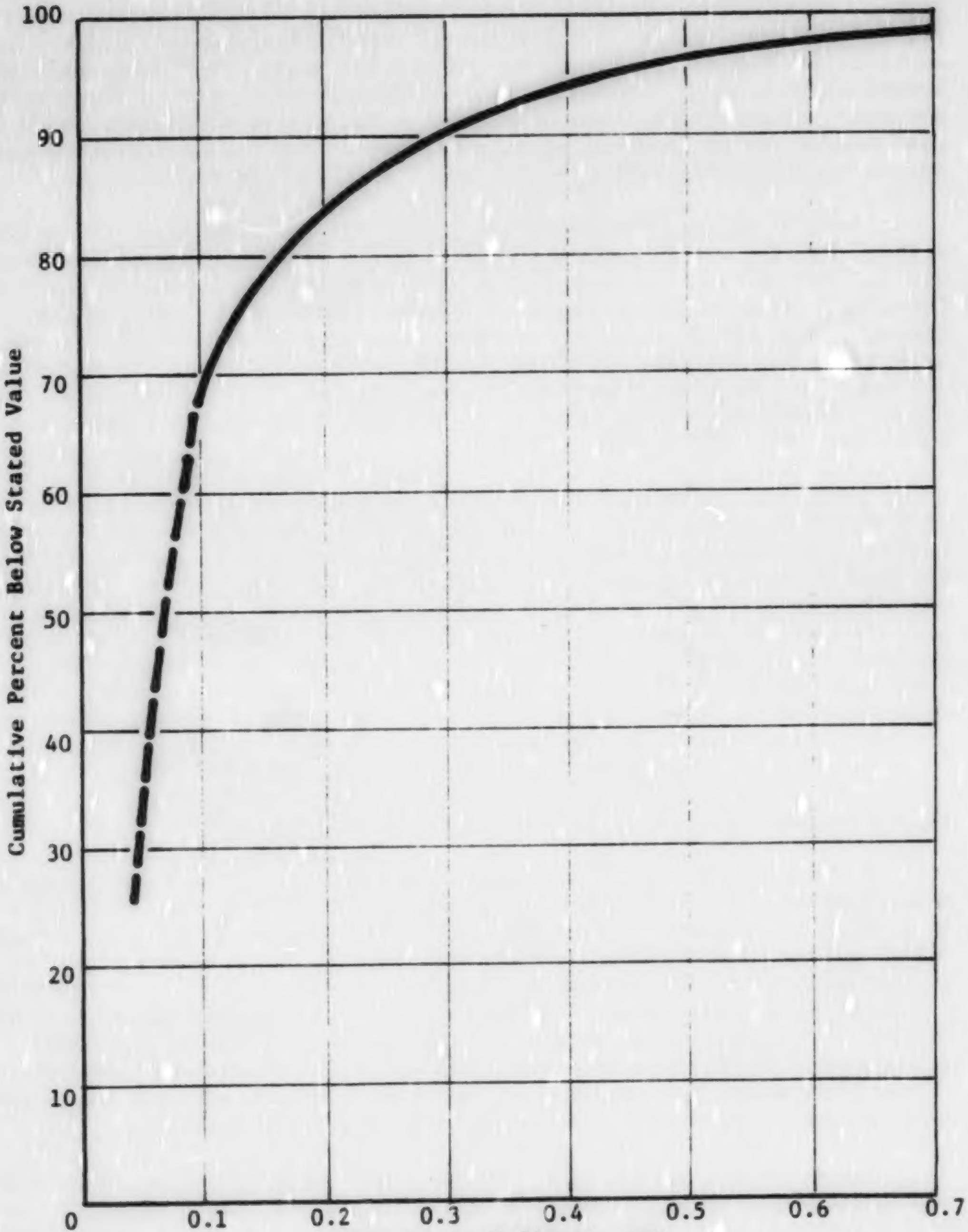

Figure 2.6. Frequency distribution of mercury in Great Lakes sediments (U.S. Environmental Protection Agency, 1976a).

More recent data confirm the generally low level of mercury in drinking water supplies, as indicated by Table 2.10 which summarizes mercury monitoring data for 1975 and 1976 taken from the computer data base maintained by the Basic Data Unit of the Water Supply Division of the Environmental Protection Agency (Kent, 1976). Of the total of 512 readings, 506 were below 2 ppb; of these, 460 (89.8 percent) were below the detection limit (0.5 ppb). Only six samples (1.2 percent) exceeded 2 ppb.

SLUDGE

In sludge resulting from the treatment of wastewater, mercury has not commonly been included in the metals for which analyses have been done, and analytical data are fairly sparse. However, the data reported below are widely dispersed geographically, and are believed to be representative of U.S. sludge mercury levels.

Salotto et al. (1974) reported the results of the analysis by the Environmental Protection Agency of about 100 digested sludge samples collected from 33 wastewater treatment plants in 13 states during the period from the summer of 1971 through 1973. They found the distribution of metals concentrations, including mercury, to characteristically have a lognormal distribution. The arithmetic mean mercury concentration was 10 ppm, the geometric mean was 6.5 ppm, and the median was 6.6 ppm. They also found that the variation of any metal in sludges from a given plant was less than the plant-to-plant variation.

In another geographically broad-based study, Furr et al. (1976) reported the analyses for 68 elements in sludge samples collected during 1972-1973 from 16 U.S. cities. Mercury concentrations were as follows:

	Hg, ppm		Hg, ppm
Atlanta GA	6.9	Milwaukee WI	3.4
Cayuga Heights NY	10.8	New York NY	15.0
Chicago IL	6.1	Philadelphia PA	4.7
Denver CO	3.6	San Francisco CA	18.0
Houston TX	3.8	Schnectady NY	9.1
Ithaca NY	13.6	Seattle WA	8.2
Los Angeles CA	7.1	Syracuse NY	6.4
Miami FL	15.5	Washington DC	5.8

The mean concentration of these analyses is 8.5 ppm; and the median is 7.0 ppm, in good agreement with Salotto's mean and median values. The extreme variability evident in concentrations of such heavy metals as cadmium was absent for mercury. The highest value was only five times as great as the lowest, whereas for lead and cadmium the ratio ranged from 55 to 65.

Very few data have been published which permit estimation of trends in mercury levels in sludges. One piece of evidence comes from Chicago, which since 1969 has had an Industrial Waste Ordinance which has limited the levels

TABLE 2.10. MERCURY IN DRINKING WATER SUPPLIES

State	Number of Analyses, <0.0005 ppm	Number of Analyses, ≥0.005 ppm	Total Number of Analyses	Maximum Concentration, ppm
Alabama		1	1	0.0030
Alaska	16	1	17	0.0005
Arizona	3		3	<0.0005
Arkansas	1		1	<0.0005
California	7	3	10	0.0010
Colorado	4		4	<0.0005
Connecticut	1		1	<0.0005
Delaware	36	12	48	0.0010
Florida	1	3	4	0.0010
Georgia	1	1	2	0.0025
Idaho	1		1	<0.0005
Illinois	7		7	<0.0005
Indiana	9		9	<0.0005
Iowa	11		11	<0.0005
Kansas	4		4	<0.0005
Kentucky	4	1	5	0.0010
Louisiana	2		2	<0.0005
Maine	13	3	16	0.0013
Maryland	22		22	<0.0005
Massachusetts	30	1	31	0.0005
Michigan	8		8	<0.0005
Minnesota	1		1	<0.0005
Mississippi	1		1	<0.0005
Missouri	3		3	<0.0005
Montana	14		14	<0.0005
Nebraska	3	1	4	0.0010
New Jersey	2		2	<0.0005
New Mexico	1		1	<0.0005
New York	83	12	95	0.0010
North Dakota	16	2	18	0.0010
Ohio	15		15	<0.0005
Oklahoma	1		1	<0.0005
Oregon	1		1	<0.0005
Pennsylvania	23		23	<0.0005
Rhode Island	1		1	<0.0005
South Carolina	3	1	4	0.2350
South Dakota	57	3	60	0.0015
Tennessee	3	1	4	0.0028
Texas	2		2	<0.0005
Utah	11	1	12	0.0010
Vermont	2	1	3	0.0005
Virginia	5	1	6	0.0115
Washington	3	1	4	0.0011
West Virginia	7		7	<0.0005
Wisconsin	4		4	<0.0005
Wyoming	4	1	5	0.0037
Guam	13		13	<0.0005
Puerto Rico		1	1	0.0015
Total	460	52	512	

Source: Kent, 1976. Drinking water in Washington, D.C., Hawaii, New Hampshire, and North Carolina was not studied.

of heavy metals discharged to the sewer system (Zenz et al., 1975). The effect on mercury levels is illustrated by average mercury concentrations in sludge at the Calumet Sewage Treatment Plant:

Year	Sludge Source	Concentration, ppm
1969	Lagoons	3.3
1972	Anaerobic digester	3.0
1974	Anaerobic digester	2.15

The national average mercury content of sludges was estimated by EPA (U.S. Environmental Protection Agency, 1974) as 5 ppm, with 10 percent of the sludge samples having in excess of 15 ppm.

Disposal options for sludge are fairly limited. Disposition in 1975 in the U.S. has been reported to be 15 percent in the ocean, 25 percent in landfills, 35 percent by incineration, and 25 percent by application to land (CAST, 1976).

Sludge contains small amounts of the fertilizer elements nitrogen, phosphorus, and potassium, and one method of disposal is to spread it on agricultural land. However, the sludge also contains most of the toxic elements present in the raw wastewater, since these tend to distribute to the sludge, and the heavy metal content is one of the factors determining acceptable rates of application of sludge to land. In the case of mercury, this has not been a great concern. The Council for Agricultural Science and Technology (1976) in assessing the agricultural implications of land disposal of sludge noted that "most sludges are relatively low in mercury, and very little increase in concentration of mercury in plants has resulted from applications of sludge".

Incineration of sludge reduces it to a dry, compact residue and simplifies its disposal. However, as an energy-intensive process, incineration is less favored than previously. Additionally, the process had some air pollution problems, one of which was mercury, since most of it volatilized and escaped to the atmosphere. Recent EPA regulations (U.S. Environmental Protection Agency, 1975c) restrict the allowable mercury emissions from sludge incinerators to 3,200 g/day, equivalent to the incineration of approximately 640,000 kg (1,410,000 lb) of sludge, assuming 5 ppm mercury content and total emission to the atmosphere of the contained mercury.

ROCKS AND SOILS

Detectable concentrations of mercury are found in virtually all types of rock, whether igneous, sedimentary, or metamorphic, as illustrated by the summarized tabulation (Table 2.11) from Krenkel et al. (1973). Sedimentary rock types generally contain more mercury (mean concentrations of 0.055 to 0.437 ppm) than metamorphic (0.05 to 0.225 ppm) or igneous rocks (0.02 to 0.168 ppm).

TABLE 2.11. MERCURY CONTENT OF ROCK TYPES

Rock Type	Mercury Concentration, ppm	
	Mean	Range
Igneous Rocks		
Ultrabasic (dunites, kimberlites, etc.)	0.168	0.007-0.25
Basic rocks		
Intrusives (gabbro, diabase, etc.)	0.028	0.005-0.084
Extrusives (basalts, etc.)	0.020	0.005-0.040
Intermediate rocks		
Intrusives (diorites, etc.	0.038	0.013-0.064
Extrusives (andesites, etc.)	0.066	0.02-0.2
Acid rocks		
Intrusives (granite, granodiorites, syenite, etc.)	0.062	0.007-0.2
Extrusives (rhyolite, trachote, etc.)	0.062	0.002-0.2
Sedimentary Rocks		
Sandstone, arkose, conglomerate, etc.	0.055	<0.01-0.3
Shales and argillites		
Shales, mudstones, argillites	0.067	0.005-0.3
Carbonaceous shales, bituminous shales, etc.	0.437	0.1-3.25
Limestone, dolomite, etc.	0.04	0.1-0.22
Evaporites		
Gypsum, anhydrite	0.025	0.01-0.06
Halite, sylvite, etc.	0.03	0.02-0.2
Metamorphic Rocks		
Quartzites	0.053	0.01-0.1
Amphibolites	0.05	0.03-0.09
Harnfels	0.225	0.035-0.4
Schists	0.1	0.01-1.0
Gneisses	0.05	0.025-0.1
Marble, crystalite, dolomite, etc.	0.05	0.01-0.1

Source: Krenkel et al., 1973.

Since rocks are the precursors of soils, mercury content in soils undisturbed by man would be expected to approximate those found in rocks. This appears to be the case, as evidenced by results of U.S. soil studies conducted by the U.S. Geological Survey (Shacklette et al., 1971). Samples (912) of soils and other regoliths (loose surface rocks) were collected from sites approximately 59 miles apart throughout the United States. The geometric mean of all samples was 0.071 ppm (0.112 ppm arithmetic mean). The geometric mean for the United States east of the 97th meridian was 0.096 ppm (0.147 ppm arithmetic mean); the geometric mean for the western United States was 0.055 ppm (0.083 ppm arithmetic mean). Of all locations sampled, 67 percent contained less than 0.080 ppm, and only 16 percent exceeded 0.175 ppm.

In a similar survey covering 29 eastern states, Wiersma and Tai (1974) found no significant difference between mercury concentrations in cropland and noncropland. Geometric means were 0.063 and 0.54 ppm, and arithmetic means were 0.08 and 0.07 ppm, respectively. These average values were not significantly different from the averages found by Shacklette et al. for western states.

Additional data on mercury concentrations in U.S. soils are available from the Environmental Protection Agency's 1972 National Soils Monitoring Program. Results of mercury analyses are shown in Table 2.12 (Gowen et al., 1973). In each Standard Metropolitan Statistical Area (SMSA) except Fitchburg, Massachusetts, urban area soils had significantly higher mercury concentrations than the corresponding suburban area soils. A number of the values for suburban soils appeared to be exceptionally low in light of the U.S. soil averages determined by Shacklette et al. (1971) and Wiersma and Tai (1974). Closer agreement was exhibited by the results of a similar National Soils Monitoring Program the following year at five different cities (U.S. Environmental Protection Agency, 1974a), which are also summarized in Table 2.12. As in the previous study, mercury levels in urban soils were found to be significantly higher than those in suburban soils; average suburban soil concentrations (geometric means) ranged from 0.03 to 0.17 ppm, consistent with Shacklette and Wiersma and Tai. The Tacoma, Washington, results may be atypical since this is the site of a large copper smelter noted for the variety of feed materials which it processes.

One of the principal noncrop uses of mercurial fungicides is on grass of the greens at golf courses which are particularly susceptible to fungus diseases. Thus, mercury content of golf-course soils can be elevated, as evidenced by the findings of an unpublished EPA study of 94 golf courses in the northern and central United States (U.S. Environmental Protection Agency, 1974b). The arithmetic mean for greens and fairway cores were as follows:

	Mercury Concentration, ppm	
Soil Core Depth	Greens	Fairways
0.0-10.1 cm	72.7	6.8
10.1-20.3 cm	30.5	0.97
20.3-30.5 cm	14.1	0.52

TABLE 2.12. CONCENTRATIONS OF MERCURY IN URBAN AND SUBURBAN SOILS

	Mercury Concentration, ppm				
Location	Number of Samples	Arithmetic Mean	Geometric Mean	Range	Positive Detection, %
Washington DC[a]					
Urban	52	0.48	0.25	0.07-7.81	
Suburban	64	0.16	0.13	0.03-1.12	
Evansville IN[a]					
Urban	34	0.27	0.16	0.04-3.55	
Suburban	30	0.09	0.08	0.04-0.25	
Pittsfield MA[a]					
Urban	40	0.33	0.25	0.11-2.51	
Suburban	5	0.17	0.15	0.07-0.27	
Greenville SC[a]					
Urban	24	0.17	0.12	0.06-1.19	
Suburban	62	0.10	0.09	0.05-0.27	
Tacoma WA[a]					
Urban	47	0.76	0.42	0.08-7.90	
Suburban	48	0.19	0.17	0.10-0.54	
Des Moines IA[b]					
Urban	59	0.44	0.103	0.00-15.39	89
Suburban	25	0.01	0.004	0.00-00.15	16
Fitchburg MA[b]					
Urban	26	0.34	0.290	0.08-00.83	100
Suburban	10	0.24	0.167	0.00-00.50	90
Lake Charles LA[b]					
Urban	16	0.06	0.020	0.00-00.29	50
Suburban	54	0.01	0.002	0.00-00.18	7
Pittsburgh PA[b]					
Urban	51	0.64	0.459	0.11-02.09	100
Suburban	138	0.09	0.044	0.00-00.74	68
Reading PA[b]					
Urban	10	0.63	0.292	0.04-02.84	100
Suburban	41	0.10	0.080	0.00-00.44	93

[a] Source: U.S. Environmental Protection Agency, 1974a, 1973 data.

[b] Source: Gowen et al., 1973, 1972 data.

The maximum value found (0 to 10 cm sample) was 338 ppm. Since neither greens nor fairways are tilled, the above-background mercury concentrations at depths of up to 30 cm are evidence of migration of applied mercurial fungicides.

TERRESTRIAL BIOTA

Vegetation

Mercury concentrations in tree species of unpolluted areas such as Cades Cove, Tennessee, in the Great Smokey Mountains and Lake Powell, Utah, average 0.02 to 0.03 ppm (Shacklette, 1970; Huckabee, 1973). In the more urban areas of Missouri and New Haven, Connecticut, concentrations are higher, ranging from 0.2 to 1.0 ppm (Shacklette, 1970; Smith, 1972). In New Haven it is interesting to note that even at 14 km from the city, mercury concentrations are similar to those in the city. In studies of vegetation in the vicinity of a New Haven oil-fired power plant, mercury concentrations did not vary significantly with distance and in general were similar to levels found throughout the city (Mondano and Smith, 1974). Ohio levels were found up to 0.03 ppm, similar to Cades Cove and Lake Powell. In contrast, trees and shrubs at Red Devil, Alaska, growing in soil over a cinnabar (HgS) vein, contain almost a hundred times more mercury, 1.0 to 1.25 ppm (Shacklette, 1970). Mercury levels vary between leaves and twigs, however, with no consistent trend. In some instances levels are higher in leaves, in others, stems.

As was the case for trees and shrubs, mercury levels found in herbaceous growth in unpolluted areas generally range from 0.02 to 0.03 ppm. Ohio, Utah, and Nevada have these levels (Devendorf, 1975; Standiford et al., 1973; Gay, 1976). The effect of air pollution from a copper smelter is evident in the data from Tacoma, Washington, where mercury concentrations in garden vegetables ranges from 1.1 to 4.0 ppm within 3.2 km of the facility (Ratsch, 1974). Levels do decrease with distance from this facility. However, even at 9.7 km, levels are ten times higher than those in unpolluted areas.

Mercury concentrations found in grasses do not exceed the 0.02 to 0.03 ppm found in trees, shrubs, and herbs under unpolluted conditions. Even samples near a stack emitting fly ash in Oak Ridge, Tennessee, contained only 0.025 ppm (Huckabee, 1973).

Mosses and lichens have a tendency to accumulate more mercury than trees, shrubs, grasses, or herbs, even in unpolluted areas. For example, at Cades Cove, Tennessee, mercury concentration in trees, shrubs, herbs, and grasses averaged 0.02 to 0.03 ppm, whereas levels in mosses ranged from 0.092 to 0.118 ppm (Huckabee, 1973). Levels in mosses and lichens in New Haven, Connecticut, are again higher than they were in other plant types, averaging over 1.0 ppm (Mondano and Smith, 1974). Mosses and lichens in all other sample areas except Oak Ridge, Tennessee, 1.18 ppm (Huckabee, 1973), contained levels similar to those found at Cades Cove. Some variation does exist, however, the tendency is toward higher concentrations in areas of higher population and industry (Yeaple, 1972).

Mammals

Levels of mercury found in mammals vary among regions of the U.S., among species, within species, and with age. There are no national sampling programs for mammals and few local studies have emphasized this group of animals. Cumbie (1975a,b) and Cumbie and Jenkins (1974) have shown that mercury levels in mammals vary among physiographic provinces in the Southeast (Table 2.13). Body burdens increase toward the coast, with levels being highest in the Lower Coastal Plain, intermediate in the Upper Coastal Plain, and lowest in the Piedmont. This has also been shown to occur with other metals (Cumbie 1975a) and may be a result of different levels of soil mineralization in the provinces.

Lynch (1973) indicates that squirrels in rural areas may accumulate higher mercury levels than those in urban environments; this is thought to be related to the ingestion of seeds treated with mercurial fungicides. Levels may also vary among species; herbivorous species such as deer and livestock tend to have lower levels than omnivorous and carnivorous species such as fox and mink. Carnivores which feed at least in part on aquatic organisms tend to accumulate the highest levels of mercury. Bioaccumulation is also illustrated by the fact that adults tend to have higher levels than young animals. Mercury concentrates at different rates in different parts of the body. Concentration values tend to be highest in hair (dry weight basis), intermediate in liver (wet weight), and lowest in muscle, fat, and milk (wet weight). On a dry weight basis, mercury levels are probably greatest in the liver (Cumbie, 1975a).

Birds

Mercury occurs in birds in all parts of the U.S. The amounts vary among years, seasons, regions, and bird species. A nationwide monitoring program in starlings revealed declining mercury levels, which were attributed to the decline in the use of pesticides and more stringent discharge requirements (Table 2.14). No differences were detected between urban and rural environments.

A national survey of mercury in woodcocks illustrates that mercury levels in birds may vary in different regions of the U.S. (Clark and McLane, 1974) (Table 2.15). Woodcock in the southern U.S. contained more mercury than those in the North; this was presumed to reflect greater ambient levels of mercury in the South. A national study of mercury levels in duck wings also demonstrates regional differences (Heath and Hill, 1974). Ducks collected in the Atlantic and Pacific flyways had greater levels of mercury than those from the Mississippi and central flyways (Table 2.16).

In addition, Heath and Hill (1974) show that differences in concentrations may occur in similar species; black duck levels were about twice as high as mallard levels. This is probably related to the fact that black ducks are more carnivorous and thus higher on the food chain. Species differences are illustrated when diving and sea ducks were shown to have considerably higher mercury levels than dabbling (pubble) ducks (Table 2.17)

TABLE 2.13. MERCURY LEVELS IN TERRESTRIAL MAMMAL HAIR

Location	Organism	Concentration, ppm wet weight		Reference
		Mean	Range	
Florida				
Statewide	Raccoon, Procyon lotor, adult	6.52[a]		Cumbie, 1975a
	Raccoon, P. lotor, juvenile	2.65[a]		
Northern	Raccoon, P. lotor	7.50[a]	0.52-35.7	Cumbie & Jenkins, 1974
Southern		4.35[a]	0.84-10.1	
Alachua County	Raccoon, P. lotor, adult	10.1[a]		Cumbie, 1975a
	Raccoon, P. lotor, juvenile	2.65[a]		
Dade County	Raccoon, P. lotor, adult	6.38[a]		
	Raccoon, P. lotor, juvenile	40.1[a]		
Eglin Air Force Base	White-tailed deer, Odocoileus virginianus		0.13-0.4[a]	Cumbie & Jenkins, 1974
Georgia		4.4[a]		Cumbie, 1975a.
Piedmont	Bobcat, Lynx rufus	ND[a]		
	Gray fox, Urocyon cinereoargenteus	2.39[a]	0.39-23.4	Cumbie & Jenkins, 1974
	Mink, Mustela vison	0.50[a]	ND-1.06	
	Opossum, Didelphis virginiana	10.7[a]	2.3-17.3	Cumbie, 1975b
	Otter, Lontra canadensis	1.30[a]	0.39-3.31	Cumbie & Jenkins, 1974
	Raccoon, P. lotor	15.9[a]	9.3-26.8	Cumbie, 1975b
	White-tailed deer, O. virginianus	0.13	ND-0.59[a]	
Upper Coastal Plain and lower coastal plain	Bobcat, L. rufus	13.05[a]	1.14-24.0	Cumbie, 1975a
	Raccoon, P. lotor	7.36	0.31-15.2	
Lower Coastal Plain	Bobcat, L. rufus	0.93[a]	0.22-2.31	
	Gray fox, U. cinereoargenteus	0.76[a]	0.82-8.41	
	Mink, M. vison	10.7[a]	5.9-15.4	Cumbie, 1975b
	Opossum, D. virginiana	2.39[a]	0.39-23.4	Cumbie & Jenkins, 1974
	Otter, L. canadensis	37.6[a]	15.8-67.9	Cumbie, 1975b
	Raccoon, P. lotor	6.12[a]	0.23-50.6	Cumbie & Jenkins, 1974
	Red fox, Vulpes vulpes	0.49[a]	0.19-0.26	
	White-tailed deer, O. virginianus		ND[b]-0.21[a]	

TABLE 2.13. (Continued)

Location	Organism	Concentration, ppm wet weight		Reference
		Mean	Range	
Piedmont				
Upper Coastal Plain	Opossum, *D. virginiana*	0.28[a]	0.16-0.38	
	Raccoon, *P. lotor*	1.55[a]	0.28-3.81	
	Red fox, *V. vulpes*	2.34	0.06-5.67	
	White-tailed deer, *O. virginianus*	0.55[a]	0.24-0.98	

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[a] Values in ppm dry weight.

[b] All data collected 1972-1973.

TABLE 2.14. MERCURY LEVELS IN STARLINGS (STURNUS VULGARIS); 1970, 1971, AND 1973[a]

Location	Concentration, ppm wet weight[b] 1970	1971	1973
Alabama			
Marion	<0.05		
Mobile		0.07	0.07
Tallaega	<0.05		
Arizona			
Graham	<0.05		
Maricopa	<0.05		
Navajo	<0.05		
Phoenix		0.01	<0.01
Yavapi	<0.05		
Arkansas			
Lonoke/Pulaski	0.05		
Stuttgart		0.06	0.03
Yell/Pope	<0.05		
California			
Bakersfield		0.05	<0.01
Colusa	0.05		
Imperial	0.09		
Inyo	0.08		
Kern	<0.08		
Los Angeles		0.01	<0.01
Modoc	0.07		
Monterey	<0.05		
Sacramento		0.04	0.06
Shasta	<0.05		
Stanislaus	0.07		
Ventura	<0.05		
Colorado			
Adams	<0.05		
Brighton			<0.01
Greeley		0.02	
Colorado			
La Plata and Rio Grande	<0.05		
Montrose	0.05		
Otero	<0.05		
Connecticut			
Connecticut River Valley		0.03	<0.01
New London	0.05		
Delaware			
Dover		0.03	
Florida			
Bay	<0.05		
Gainesville		0.21	<0.01
Hardee	<0.05		
Madison	<0.05		
Polk	<0.05		
Georgia			
Atlanta		0.03	0.01
Pike	<0.05		
Wayne	<0.05		
Idaho			
Boise		0.07	<0.01
Franklin	<0.05		
Minidoka	0.06		
Nezperce	0.05		
Owyhee	0.05		
Illinois			
Chicago		0.01	<0.01
Cook	0.07		

TABLE 2.14. (Continued)

Location	Concentration, ppm wet weight^b		
	1970	1971	1973
Illinois (cont'd)			
Sagamon	<0.05		
Stephenson	<0.05		
Indiana			
Evansville			<0.01
Gary			0.01
Henry	0.19		
Highland		0.02	
Iowa			
Butler	<0.05		
Polk	<0.05		
Pottawattomie	<0.05		
Des Moines		Not detected	<0.01
Kansas			
Garden City		<0.01	0.01
Hamiltion & Kearny	0.15		
Marion	0.15		
Nemaha	0.18		
Rowlins	0.10		
Smith	0.07		
Kentucky			
Hopkins	0.10		
Ohio	<0.05		
Louisiana			
Baton Rouge		0.05	0.02
Jefferson	<0.05		
Rapides	0.10		
Maine			
Gray		0.06	<0.01
Penobscot	0.05		
Maryland			
Annapolis			<0.01
Patuxent		<0.01	<0.01
Prince George	0.10		
Massachusetts			
Quincy		0.05	<0.01
Michigan			
Chippewa	0.05		
Grand Traverse	0.06		
Inaham	0.05		
Kent	0.05		
Lansing		0.03	<0.01
Minnesota			
Aitkin	<0.05		
Pine	<0.05		
Swift	<0.05		
Twin Cities		0.01	<0.01
Mississippi			
Harrison	<0.05		
Jackson	0.08		
Leake	<0.05		
Starkville		0.01	<0.01
Missouri			
Bollinger	<0.05		
Malden		0.02	0.01
Stoddard	0.05		
Montana			
Meagher	0.06		
Missoula	<0.05		

TABLE 2.14. (Continued)

Location	Concentration, ppm wet weight[b]		
	1970	1971	1973
Montana (cont'd)			
Richland	0.08		
Yellowstone	<0.05		
Nebraska			
Antelope	<0.05		
Clay	<0.05		
Keith	0.05		
Lincoln	<0.05		
North Platte		0.01	0.01
Nevada			
Clark	0.06		
Humboldt	0.06		
McGill		0.05	<0.01
Nye	0.09		
Reno		0.02	0.20
White Pine	0.11		
New Jersey			
New Brunswick		0.22	<0.01
New Mexico			
Bernalillo	<0.05		
Carlsbad		0.05	<0.01
Chaves	<0.05		
Farmington		0.025	<0.01
Luna	0.08		
Quay	<0.05		
Santa Fe & Torrence	<0.05		
New York			
Albany			<0.01
Jamestown		0.03	<0.01
Oswego	0.06		
New York			
Rennselaer	0.10		
North Carolina			
Macon	<0.05		
Pender	<0.05		
Raleigh		0.01	<0.01
Union	<0.05		
Wilkes	0.05		
North Dakota			
Bismarck			0.01
Cavelier	0.11		
Dickey	<0.05		
Manden		0.02	
Ward	0.05		
Ohio			
Columbus		0.06	0.06
Erie	0.11		
Jefferson	<0.05		
Washington	0.08		
Oklahoma			
Canadian	0.13		
Greer	0.08		
Nowata	0.13		
Okmulgee	0.09		
Tishomingo		0.01	<0.01
Oregon			
Baker	0.14		
Corvallis		0.32	0.05
Harney	0.10		
Klamath	0.11		

TABLE 2.14. (Continued)

Location	Concentration, ppm wet weight[b] 1970	1971	1973
Oregon (cont'd)			
Lane	1.90		
Wilsonville		0.62	0.05
Yamhill	1.50		
Pennsylvania			
Cuzerne	0.10		
Pittsburgh		0.06	<0.01
Sommerset	0.10		
South Carolina			
Aiken	<0.05		
Columbia		<0.01	
South Dakota			
Brown	0.05		
Hughes	<0.05		
Pierre		0.05	0.13
Potter	<0.05		
Tennessee			
Davidson	0.05		
Nashville		0.03	<0.01
Texas			
Clay	0.08		
Hillsboro		0.04	0.01
Morris	<0.05		
San Antonio		0.03	<0.01
Utah			
Salt Lake City		0.030	0.04
Sevier/Millard	0.08		
Weber	0.09		
Utah (cont'd)			
Sevier/Millard	0.08		
Weber	0.09		
Vermont			
Addison	0.05		
Champlain Valley		0.10	
Virginia			
Amherst	0.08		
Blacksburg		0.01	0.03
Caroline	0.18		
Prince George	0.22		
Washington			
Pierce	0.05		
Spokane	0.07	<0.01	<0.01
Whitman	0.06		
Yakima	0.06	0.02	0.03
West Virginia			
Elkins		0.01	0.01
Wisconsin			
Curtiss	0.05		
Horicon		0.03	
Portage			0.03
Tempeleau	<0.05		
Wyoming			
Big Horn	0.05		
Brook	<0.05		
Goshen	<0.05		
Washakie	0.06		
Worland			0.01

[a] Sources: For 1970 - Martin (1972); 1971 - Martin and Nickerson (1973); 1973 - White et al. (1976).
[b] Each value represents analysis of a composite of 10 starlings.

TABLE 2.15. MERCURY LEVELS IN WOODCOCK
(*PHILOHELA MINOR*) LIVER, 1970-1971

Location	Number of Samples	Concentration, ppm wet weight	
		Mean	Range
Alabama	5	0.61	0.29-0.92
Arkansas	5	0.17	0.06-0.26
Florida	4	0.28	0.18-0.36
Georgia	5	0.17	0.05-0.23
Kentucky	5	0.09	0.05-0.14
Louisiana	9	0.25	0.13-0.36
Maine	5	0.07	0.05-0.12
Maryland	5	0.22	0.14-0.28
Michigan	5	0.09	0.05-0.12
Minnesota	5	0.06	0.05-0.08
Mississippi	10	0.17	0.08-0.27
Missouri	4	0.13	0.05-0.17
New Hampshire	4	0.09	0.07-0.12
New Jersey	9	0.19	0.08-0.46
New York	5	0.15	0.08-0.23
North Carolina	5	0.37	0.05-0.87
Pennsylvania	5	0.10	0.07-0.17
Rhode Island	4	0.13	0.05-0.22
South Carolina	5	0.57	0.17-1.10
Tennessee	4	0.35	0.20-0.66
Vermont	4	0.09	0.07-0.12
West Virginia	5	0.08	0.05-0.14
Wisconsin	5	0.10	0.05-0.15

Source: Clark and McLane, 1974.

TABLE 2.16. MERCURY LEVELS IN BLACK DUCK AND MALLARD WINGS (*AMAR RUBRIPES* AND *A. PLATYHYNCHER*), 1969-1970

Location	Organism	Number of Samples	Concentration, ppm wet weight Mean	Concentration, ppm wet weight Range
Atlantic Flyway				
Connecticut	Black duck	3	0.21	0.14-0.24
Delaware	Black duck	2	0.20	0.15-0.25
Florida and Georgia	Mallard	2	0.12	0.09-0.18
Maine	Black duck	3	0.19	0.16-0.24
Maryland	Black duck	3	0.11	0.10-0.13
	Mallard	2	0.08	0.08-0.08
Massachusetts	Black duck	4	0.22	0.21-0.22
New Hampshire	Black duck	2	0.20	0.20-0.20
New Jersey	Black duck	5	0.18	0.15-0.23
	Mallard	3	0.11	0.10-0.12
New York	Black duck	4	0.33	0.18-0.80
	Mallard	3	0.11	0.09-0.12
North Carolina	Black duck	2	0.15	0.14-0.16
Pennsylvania	Black duck	3	0.16	0.12-0.19
	Mallard	3	0.08	0.06-0.10
Rhode Island	Black duck	3	0.19	0.14-0.22
South Carolina	Black duck	2	0.18	0.18-0.19
	Mallard	3	0.13	0.11-0.15
Vermont	Black duck	2	0.26	0.14-0.39
Virginia	Black duck	3	0.15	0.13-0.17
	Mallard	2	0.16	0.15-0.16
Mississippi Flyway				
Alabama	Mallard	1	0.06	
Arkansas	Mallard	6	0.08	0.06-0.10
Indiana	Mallard	1	0.06	
Illinois	Mallard	6	0.06	0.05-0.08
Iowa	Mallard	4	0.08	0.06-0.10
Kentucky	Mallard	1	0.09	
Louisiana	Mallard	5	0.08	0.06-0.09
Michigan	Mallard	3	0.11	0.08-0.14
Minnesota	Mallard	5	0.08	0.06-0.10
Mississippi	Mallard	2	0.08	0.07-0.08
Missouri	Mallard	5	0.07	0.05-0.11
Ohio	Mallard	3	0.10	0.08-0.12
Tennessee	Mallard	4	0.08	0.07-0.12
Wisconsin	Mallard	5	0.26	0.05-1.00
Central Flyway				
Colorado	Mallard	4	0.08	0.07-0.10
Kansas	Mallard	6	0.06	Trace-0.09

TABLE 2.16. (Continued)

Location	Organism	Number of Samples	Concentration, ppm wet weight Mean	Range
Central Flyway (cont'd)				
Montana	Mallard	4	0.07	0.05-0.09
Nebraska	Mallard	7	0.09	0.07-0.13
New Mexico	Mallard	3	0.09	0.06-0.10
North Dakota	Mallard	6	0.08	0.06-0.11
Oklahoma	Mallard	4	0.08	0.05-0.11
South Dakota	Mallard	6	0.06	0.05-0.09
Texas	Mallard	6	0.06	0.05-0.07
Wyoming	Mallard	3	0.08	0.07-0.09
Pacific Flyway				
Arizona and New Mexico	Mallard	3	0.12	0.09-0.14
California	Mallard	8	0.08	0.05-0.11
Colorado	Mallard	3	0.10	0.09-0.12
Idaho	Mallard	8	0.10	0.08-0.15
Montana	Mallard	4	0.10	0.10-0.11
Nevada	Mallard	3	0.37	0.23-0.55
Oregon	Mallard	7	0.09	0.06-0.10
Utah	Mallard	5	0.09	0.06-0.10
Washington	Mallard	8	0.09	0.05-0.18
Wyoming	Mallard	2	0.12	0.10-0.13

Source: Heath and Hill, 1974.

TABLE 2.17. MERCURY LEVEL IN DUCK BREAST MUSCLE, 1970-1971

Location Location	Organism	No. of Samples	Concentration, ppm wet weight	
			Mean	Range
Alabama				
Baldwin County	Gadwall, *Anas strepera*	4	0.06	0.02-0.09
	Lesser scaup, *Aythya affinis*	9	0.21	0.12-0.34
Mobile County	Gadwall, *Anas strepera*	12	0.89	0.08-3.90
	Lesser scaup, *Aythya affinis*	7	0.48	0.14-2.00
California				
San Francisco Bay	Greater scaup, *Aythya marila*	8	0.38	0.09-0.68
	Lesser scaup, A. *affinis*	4	0.27	0.03-0.68
	Mallard, *Anas platyrhynches*	16	0.16	0.02-1.06
	Pintail, *A. acuta*	5	0.09	0.05-0.15
Tule Lake NWR	Lesser scaup, *Aythya affinis*	16	0.37	0.02-1.77
	Mallard, *Anas platyrhynches*	16	0.14	0.02-1.47
Maryland				
Chesapeake Bay	Canvasback, *Aythya valisineria*	8	0.14	0.05-0.24
	Common scoter, *Melanitta nigra*	3	0.12	0.06-0.20
	Mallard, *Anas platyrhynches*	8	0.03	0.01-0.06
	Surf scoter, *Melanitta perspicillato*	1	0.17	
	White-winged scoter, *M. deglandi*	4	0.30	0.07-0.61
West River	Canvasback, *Aythya valisineria*	8	0.10	0.08-0.16
Minnesota				
Agassiz	Mallard, *Anas platyrhynches*	16	0.11	0.03-0.24
Itasca	Lesser scaup, *Aythya affinis*	8	0.16	0.07-0.25
North Carolina				
Corolla	Lesser scaup, A. *affinis*	7	0.28	0.10-0.47
	Mallard, Anas *platyrhynches*	8	0.07	0.03-0.12
Grandy	Mallard, A. *platyrhynches*	8	0.03	<0.01-0.16
Pamlico Pt.	Lesser scaup, Aythya *affinis*	8	0.21	0.03-0.70
North Dakota				
Audubon NWR	Mallard, Anas *platyrhynches*	8	0.04	0.01-0.10
Pettibone	Mallard, A. *platyrhynches*	7	0.09	0.03-0.18
Stanton	Mallard, A. *platyrhynches*	6	0.02	0.02-0.03
Woodworth	Lesser scaup, *Aythya affinis*	16	0.31	0.04-0.70
	Mallard, *Anas platyrhynches*	8	0.03	0.01-0.05
South Dakota				
MacPhearson	Lesser scaup, *Aythya affinis*	6	0.16	0.09-0.19
	Mallard, *Anas platrhynches*	8	0.03	0.02-0.06
Marshall County	Lesser scaup, *Aythya affinis*	8	0.31	0.15-0.65
Sandlake NWR	Mallard, *Anas platrhynches*	8	0.03	0.02-0.05
Texas				
Port Lavaca	Lesser scaup, *Aythya affinis*	16	0.28	0.06-1.00
	Mottled duck, *Anas fulvigula*	16	0.26	0.07-0.43
Vermont				
Lake Champlain	Black duck/Mallard, *Anas rubripes*/ A. *platyrhynches*	6	0.11	0.04-0.17
	Common goldeneye, *Bucephala clangula*	8	0.42	0.21-0.76
Utah				
Brigham City	Greater scaup, *Aythya marila*	1	0.02	
	Lesser scaup, A. *affinis*	2	0.13	0.12-0.14
	Mallard, Anas platyrhynches	16	0.04	0.01-0.19
	Ring-necked duck, *Aythya collaris*	3	0.11	0.06-0.18

Source: Baskett, 1975.

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(Baskett, 1975). Dabbling ducks are more herbivorous and feed in shallow water or on the ground. Diving and sea ducks are more carnivorous and feed on fish and botton-dwelling organisms which bioaccumulate mercury from the water and sediment.

Numerous local studies of total mercury levels in various species of birds have been conducted in the U.S. Several studies (Brock et al., 1973; Buhler et al., 1973) have shown that levels of mercury in birds may vary with the availability of mercury-contaminated foods. Granivorous birds had higher levels at crop-planting time when mercury-coated seeds were used than at other times of the year. Birds with access to mercury-treated seeds may have higher levels than birds from urban or nonfarm areas (Lynch, 1973). Some of the highest levels reported in birds have come from Lake St. Clair, Michigan, in recent years; however, the levels reported in bird eggs from this area have declined (Table 2.18). The decline is probably related to a decrease in the amount of mercury discharged into lakes and streams. Studies in other areas needed to corroborate the decline have not been made.

Mercury ingested by birds accumulates at different rates in different parts of the body (Table 2.19) (Buhler, 1977). Values tend to be highest in feathers but occasionally are exceeded by those in liver tissue. Liver concentrations average from two to six times higher than muscle tissue concentrations. The mercury background level for pheasants raised in captivity in Oregon is 0.001 to 0.002 ppm in muscle (Buhler, 1977). On this basis, a significant accumulation of mercury was found in over 90 percent of the Oregon pheasants collected during 1970. The mean concentration of mercury in muscle tissue from these birds was 0.173 ppm, with approximately 7.5 percent of the pheasants exceeding the 0.5 ppm FDA guideline value for mercury in foods. The highest concentrations of mercury observed in this survey occurred in one bird from the Willamette Valley that contained 6.33 ppm in breast muscle and 12.8 ppm in the liver. The concentration of mercury in Oregon pheasants varied appreciably among seasons and areas, but maximum tissue residues appeared to be related to the time of greatest availability of seeds treated with mercury fungicides in a particular area.

Almost all of the mercury found in the muscle tissue from the birds collected in 1970 was in the form of methylmercury (Table 2.20), suggesting that these birds had been exposed primarily to seeds dressed with methylmercuric dicyanidiamide. This chemical has been widely used in Oregon agriculture and in 1970 it accounted for over 80 percent of the mercury fungicide used in the state.

AQUATIC BIOTA

Levels of environmental mercury appear to be considerably highest in the tissues of aquatic biota in Atlantic coastal environs--both freshwater and marine. The sources of contamination in this region of the U.S. are primarily industrial. Regionally high values also occur in the states of the Pacific Northwest--particularly in the Columbia and Snake River drainages in Washington and Idaho. The elevated levels result from both mining activity and the leaching of soils naturally high in mercury content.

TABLE 2.18. MERCURY LEVELS IN BIRDS OF LAKE ST. CLAIR, MICHIGAN

Organism	Organ or Tissue	Concentration, ppm wet weight Mean	Concentration, ppm wet weight Range	Reference
Bald eagle, *Haliaeetus leucocephalus*	Egg	0.4		Wiemeyer et al., 1972
American bittern, *Botaurus lentiginosus*	Carcass	0.55		Dustman et al., 1972
	Liver	1.75		
Black-crowned night heron, *Nycticorax nycticorax*	Carcass	2.8		
	Liver	14.0		
	Egg	0.77	0.046-0.11	
Black tern, *Chlidonias niger*	Carcass	0.68	0.41-1.3	
	Liver	2.47	1.3-2.6	
Blue-winged teal, *Anas discors*	Breast muscle	0.68	0.10-2.3	
	Liver	1.50	0.35-5.0	
	Kidney	1.40	0.27-4.4	
Canada goose, *Branta canadensis*	Breast muscle	<0.10		
	Liver	0.18		
	Kidney	<0.10		
Common gallinule, *Gallinula chloropus*	Carcass	0.41		
	Liver	1.4		
Common tern, *Sterna hirundo*	Carcass	3.4	0.4-7.5	Dustman et al, 1972
	Liver	18.1	2.1-39.0	
	Egg	2.72	0.63-6.25	
Dunlin, *Calidris alpina*	Carcass	0.15	<0.10-0.20	
	Liver	0.95	0.70-1.3	
Great blue heron, *Ardea herodias*	Carcass	14.4	5.3-23.0	
	Liver	97.0	14.6-136.0	
Great egret, *Casmerodius albus*	Carcass	0.74		
	Liver	6.3		
Killdeer, *Charadrius vociferus*	Carcass	0.45	0.14-0.68	
	Liver	2.2	0.5-2.3	
Lesser scaup, *Aythya affinis*	Breast muscle	0.81	0.54-1.2	
	Liver	3.2	1.8-3.4	
	Kidney	2.01	0.96-2.3	

TABLE 2.18. (Continued)

Organism	Organ or Tissue	Concentration, ppm wet weight		Reference
		Mean	Range	
Mallard, *Anas platyrhynchos*	Breast muscle	0.48	<0.10-1.15	Dustman et al., 1972
	Liver	1.62	0.23-4.8	
	Kidney	1.13	<0.10-3.5	
	Egg	0.82	0.22-2.7	
Mallard, *A. platyrhynchos*	Liver	0.54 ± 0.83		Ford and Prince, 1975
Ring-billed gull, *Larus delawarensis*	Carcass	0.41	0.14-0.70	Dustman et al., 1972
	Liver	1.22	0.65-1.8	
Scaup, Aythya spp.	Liver	0.99 ± 1.00		Ford and Prince, 1975
Spotted sandpiper, *Actitis macularia*	Carcass	0.55		Dustman et al., 1972
	Liver	2.8		
Black-crowned night heron, *Nycticorax nycticorax*	Egg	0.45	0.20-0.76	Stendell et al., 1976
Common tern, *Sterna hirundo*	Egg	1.15	0.69-2.16	
Great egret, *Casmerodias albus*	Egg	0.35	0.21-0.45	
Mallard, *A. platyrhynchos*	Egg	0.077	<0.05-0.26	

TABLE 2.19. DISTRIBUTION OF MERCURY IN TISSUES OF OREGON PHEASANTS

Tissue	Total Mercury, ppm	
	Male Pheasant	Female Pheasant
Feathers	26.0	0.36
Liver	12.8	2.30
Kidney	6.93	3.46
Crop and contents	6.57	1.67
Muscle	6.33	1.14
Gizzard	5.35	1.43
Skin	5.00	0.40
Brain	4.70	0.95
Heart	4.35	2.91
Testes	2.99	--
Femur	1.11	0.19
Gizzard contents	0.93	0.54
Fat	--	0.10

Source: Buhler, 1977.

TABLE 2.20. MERCURY AND METHYLMERCURY CONTENT OF PHEASANT BREAST TISSUE

Year	Bird Number	Total Mercury, ppm	Methylmercury, ppm	Methylmercury, %
1970	14	1.14	1.3	114
	23	2.11	1.8	85.3
	26	2.71	2.6	95.9
	50	0.337	0.35	103.8
			Mean ± S.D.	99.8 ± 12.1
1972	212	0.088	0.096	110.2
	215	0.911	0.430	47.2
	220	3.032	0.324	27.2
	221	0.486	0.024	4.9
			Mean ± S.D.	47.4 ± 45.3

Source: Buhler, 1977.

Other generally isolated incidences of aquatic biota contamination occur in many states of the U.S. These levels are most often associated with a point source of mercury emission, such as sewage treatment and chlor-alkali plants, or nonpoint source runoff from agricultural or other use of mercurial fungicides.

Mercury compounds enter aquatic organisms both indirectly through the food web and directly by extraction from solution (Jernelöv and Lann, 1971; D'Itri, 1972; Peterson et al., 1973). From the available literature, it can be seen that highest accumulations occur in fishes at the top of the trophic structure, the sport fishes and piscivores. This seems to be the major pathway for mercury accumulation in predator fish. Occasionally, elevated levels were found in carp and suckers; these are due to direct extraction, with less than 25 percent of their total mercury accumulation coming through the food chain (Jernelöv and Lann, 1971). Mercury and its compounds are made available through biological methylation by microorganisms (Jensen and Jernelöv, 1969; D'Itri, 1972).

Fish

Analysis of mercury in fishes collected as part of the National Pesticides Monitoring Program (NPMP) was initiated in 1969 (Henderson et al., 1972). Data are summarized in Tables 2.21 to 2.26 by geographical region. Highest regional values were reported from the Atlantic coastal streams (Regions 4 and 5). These concentrations are likely due to industrial discharge rather than to either agricultural runoff or leaching of natural minerals. Elevated concentrations in fishes from certain areas of the Columbia and Snake Rivers in Washington and Idaho reflect contamination from both mining activity and natural occurrence. On a regional basis, overall lowest concentrations were found in Region 2, Texas, New Mexico, Arizona, and Oklahoma. On a state basis, Alaska has the lowest amount of contamination to date, less than 0.1 ppm. It should be noted, however, that only two locations were sampled in Alaska and this is not an actual assessment for the entire state.

In most cases, NPMP data reveal highest mercury concentrations in the muscle tissue of the sport fishes, particularly largemouth bass, perch, catfish, and walleye. Relatively low overall levels found in Region 6 may reflect the larger proportion of forage fishes sampled. Elevated concentrations were found in the northern squawfish, a large minnow whose range is restricted to the western states. This fish, like many of the game fishes, is a voracious piscivore. Occasionally, elevated concentrations were also found in carp and suckers. These data indicate that mercury concentration is related to feeding habit, whether indirectly through a food chain or directly from sediments.

A preliminary study from the National Marine Fisheries Service (1975) reported the levels of mercury found in the muscle tissues of marine fish species (Figure 2.7). Of the 106 species tested, only six had more than 50 percent of the samples above the FDA 0.05 ppm mercury guideline--blue marlin, white marlin, gag, little tunny, black grouper, and Hawaiian red

TABLE 2.21. LEVELS OF MERCURY IN FISH FROM REGION 1, NATIONAL PESTICIDES MONITORING PROGRAM, 1969,[a] 1970,[a] AND 1972[b]

Location	Concentration, ppm					
	Mean			Range		
	1969	1970	1972[c]	1969	1970	1972
Alaska						
Chena River	0.07	0.06	0.09	0.06-0.09	0.05-0.06	0.06-0.14
Kenai River	0.09	0.14	0.06	0.06-0.12	0.06-0.26	0.01-0.18
Calfornia						
Klamath River	0.16	0.20		0.12-0.22	0.12-0.27	
Sacramento River	0.14	0.20	0.18	0.11-0.19	0.18-0.22	0.02-0.32
San Joaquin River	0.18	0.16	0.04	0.14-0.20	0.09-0.23	0.03-0.05
Hawaii						
Manoa Stream		0.13	0.06		0.09-0.18	0.03-0.10
Waikele Stream		0.17	0.19		0.06-0.43	0.02-0.46
Idaho						
Bear River		0.23	0.11		0.13-0.37	0.06-0.14
Salmon River		0.80	0.16		0.29-1.70[d]	0.08-0.21
Snake River	0.26	0.21	0.11	0.08-1.25[d]	0.08-0.43	0.01-0.26
Nevada						
Colorado River		0.07	0.03		0.05-0.09	0.01-0.05
Truckee River	0.37	0.41	0.29	0.22-0.53[c]	0.21-0.65[c]	<0.05-0.50
Oregon						
Columbia River	0.56	0.55	0.10	0.15-1.25[d]	0.21-1.10[d]	0.08-0.23
Rouge River	0.44	0.27	0.11	0.16-0.90[f]	0.14-0.51[f]	0.04-0.18
Williamette River	0.18	0.26	0.16	0.13-0.23	0.17-0.33	0.04-0.29
Washingron						
Columbia River		0.14	0.13		0.07-0.25	0.02-0.47
Snake River Ice Harbor		0.61	0.10		0.10-1.20[d]	0.03-0.18
Yakima River	0.19	0.19	0.28	0.3-0.9[g]	0.07-0.27	0.03-0.64[d]

[a] Source: Henderson et al., 1972.
[b] Source: Berger, 1974.
[c] Calculated from author's data.
[d] Northern squawfish.
[c] Largemouth bass.
[f] Brown bullhead.
[g] Largescale sucker and smallmouth bass.

TABLE 2.22. LEVELS OF MERCURY IN FISH FROM REGION 2, NATIONAL PESTICIDES MONITORING PROGRAM, 1969,[a] 1970,[a] AND 1972[b]

	Concentration, ppm					
	Mean			Range		
Location	1969	1970	1972[c]	1969	1970	1972
Arizona						
Colorado River	<0.05	0.10	0.11	<0.05-0.05	<0.05-0.27	<0.05-0.49
Gila River		0.15	0.25		0.11-0.22	0.10-0.41
New Mexico						
Rio Grande		0.33	0.21		0.10-0.52[d]	0.16-0.28
Oklahoma						
Arkansas River	0.07	0.14	0.07	<0.05-0.14	0.06-0.22	<0.05-0.08
Canadian River		0.10			0.06-0.21	--
Red River		0.18	0.06		0.10-0.24	<0.05-0.12
Verdigris River		0.20	0.09		0.05-0.44	0.06-0.15
Texas						
Brazos River		0.13	0.11		0.05-0.24	0.06-0.17
Colorado River		0.16	0.18		0.14-0.19	0.11-0.46
Nueces River		0.17	0.03		<0.05-0.40	0.02-0.06
Pecos River		0.18	0.07		0.05-0.42	0.01-0.10
Rio Grande River	0.04	0.09	0.06	<0.05-0.06	<0.05-0.17	0.01-0.11

[a] Source: Henderson et al., 1972.

[b] Source: Berger, 1974.

[c] Calculated from author's data

[d] Largemouth bass.

TABLE 2.23. LEVELS OF MERCURY IN FISH FROM REGION 3, NATIONAL PESTICIDES MONITORING PROGRAM, 1969,[a] 1970,[a] AND 1972[b]

	Concentration, ppm					
	Mean			Range		
Location	1969	1970	1972[c]	1969	1970	1972
Illinois						
Illinois River	0.10	0.13	0.05	0.07-0.13	0.08-0.21	0.04-0.06
Ohio River		0.22	0.01		0.11-0.43	0.09-0.21
Indiana						
Wabash River		0.19	0.12		0.15-0.25	0.07-0.16
Iowa						
Mississippi River	0.16	0.20	0.12	0.10-0.25	0.11-0.33	0.08-0.18
Michigan						
Lake Huron	0.07	0.07	0.06	<0.05-0.13	0.05-0.08	<0.05-0.07
Minnesota						
Mississippi River		0.48	0.21		0.21-0.68[d]	0.09-0.46
Red River	0.39	0.31	0.53	0.36-0.41	0.13-0.60	0.32-0.75[c]
Missouri						
Mississippi River		0.14	0.07		<0.05-0.20	0.06-0.10
Ohio						
Ohio River	0.33	0.32	0.17	0.20-0.50	0.07-0.83[d]	0.06-0.24
Wisconsin						
Lake Michigan	0.18	0.09	0.24	0.09-0.27	0.07-0.09	0.12-0.26
Lake Superior	0.10	0.17	0.18	<0.05-0.16	0.06-0.29	0.08-0.28
Wisconsin River		0.37	0.073		0.11-0.60	0.01-0.15

[a] Source: Henderson et al., 1972

[b] Source: Berger, 1974.

[c] Calculated from author's data.

[d] Catfish.

[e] Sauger.

TABLE 2.24. LEVELS OF MERCURY IN FISH FROM REGION 4, NATIONAL PESTICIDES MONITORING PROGRAM, 1969,[a] 1970,[a] AND 1972[b]

Location	Concentration, ppm Mean 1969	Mean 1970	Mean 1972[c]	Range 1969	Range 1970	Range 1972
Alabama						
Alabama River		0.36	0.136		<0.05-0.60[d]	0.04-0.36
Tombigee River	0.46	0.44	0.33	0.36-0.65[d]	0.15-0.92[d]	0.01-0.96[d]
Arkansas						
Arkansas River	0.12	0.14	0.13	0.08-0.15	0.09-0.22	0.06-0.16
White River	0.21	0.19	0.17	0.13-0.27	0.12-0.35	0.11-0.27
Florida						
Apalachikola River	0.16	0.11	0.10	0.08-0.23	0.10-0.13	0.05-0.19
St. John's River	0.05	0.18	0.06	<0.05-0.08	<0.05-0.43	0.03-0.10
St. Lucie Canal	0.23	0.18	0.07	0.13-0.34	0.06-0.28	0.06-0.16
Suwannee River		0.22	0.17		0.13-0.37	0.07-0.49
Georgia						
Altamaha River		0.28	0.31		0.11-0.51	0.11-0.54
Savannah River	0.60	0.78	0.46	0.36-1.00[d]	0.17-1.80[d]	0.14-0.67[d]
Louisiana						
Mississippi River	0.16	0.14	0.11	0.11-0.22	<0.05-0.30	0.06-0.16
Red River		0.18	0.15		0.10-0.24	0.08-0.18
Mississippi						
Yazoo River		0.16	0.17		0.10-0.19	0.15-0.27
North Carolina						
Cape Fear River	0.23	0.37	0.18	0.17-0.35	0.25-0.60	0.10-0.40
Roanoke River	0.11	0.14	0.10	0.09-0.13	0.08-0.21	0.04-0.23
South Carolina						
Cooper River	0.12	0.16	0.16	0.09-0.14	0.05-0.24	0.01-0.28
Pee Dee River		0.47	0.24		0.19-1.00	0.10-0.36
Tennessee						
Cumberland River	0.16	0.10	0.17	0.09-0.27	0.05-0.15	0.04-0.34
Mississippi River		0.21	0.11		0.14-0.46	0.05-0.20
Tennessee River		0.45	0.39		0.27-0.67	0.22-0.78

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[a] Source: Henderson et al., 1972.
[b] Source: Berger, 1974.
[c] Calculated from author's data.
[d] Largemouth bass.

TABLE 2.25. LEVELS OF MERCURY IN FISH FROM REGION 5, NATIONAL PESTICIDES MONITORING PROGRAM, 1969,[a] 1970,[a] AND 1972[b]

Location	Concentration, ppm					
	Mean			Range		
	1969	1970	1972[c]	1969	1970	1972
Connecticut						
Connecticut River	0.36	0.34	0.21	0.13-0.80[d]	0.18-0.51	0.12-0.32
Maine						
Kennebee River		0.66	0.63		0.38-1.20[c]	0.23-0.99[f]
Penobscot River	0.38	0.48	0.56	0.23-0.48	0.29-0.64	0.49-0.62
Maryland						
Potomac River	0.09	0.05	0.21	0.08-0.10	<0.05-0.09	0.06-0.36
Susquehanna River	0.07	0.07	0.07	0.05-0.09	0.05-0.10	0.03-0.10
Massachusetts						
Merrimac River		0.25	0.39		0.15-0.33	0.09-0.56
New Jersey						
Delaware River	0.12	0.11	0.11	0.05-0.22	0.07-0.21	0.02-0.18
Raritan River		0.21	0.18		0.08-0.29	0.10-0.28
New York						
Genessee River	0.20	0.24	0.08	0.13-0.25	0.15-0.39	0.07-0.11
Hudson River	0.20	0.13	0.14	0.16-0.25	0.07-0.19	0.12-0.15
Lake Ontario	0.52	0.84	0.32	0.43-0.65	0.30-1.30[d]	0.24-0.47
St. Lawrence River		0.27	0.14		0.18-0.39	0.08-0.24
Pennsylvania						
Allegheny River		0.12	0.07		0.05-0.18	0.04-0.09
Lake Erie	0.13	0.31	0.13	0.10-0.15	0.15-0.43	0.04-0.16
Vermont						
Lake Champlain		0.41	0.36		0.27-0.49	0.24-0.50
Virginia						
James River		0.14	0.07		0.11-0.20	<0.05-0.12
Kanawha River	<0.05	0.06	0.04	<0.05	<0.05-0.11	0.01-0.06

---

[a] Source: Henderson et al., 1972.
[b] Source: Berger, 1974.
[c] Calculated from author's data.
[d] White perch.
[e] Yellow perch.
[f] Bass.

TABLE 2.26. LEVELS OF MERCURY IN FISH FROM REGION 6, NATIONAL PESTICIDES MONITORING PROGRAM, 1969,[a] 1970,[a] AND 1972[b]

	Concentration, ppm					
	Mean			Range		
Location	1969	1970	1972[c]	1969	1970	1972
Colorado						
Arkansas River		0.06	0.04		0.05-0.07	0.04-<0.05
Rio Grande River		0.13	0.09		<0.05-0.28	0.05-0.14
Iowa						
Des Moines River		0.17	0.06		0.07-0.24	0.03-0.09
Kansas						
Kansas River		0.18	0.05		0.08-0.33	0.02-0.07
Missouri						
Missouri River		0.11	0.08		<0.05-0.15	0.04-0.13
Montana						
Big Horn River		0.26	0.11		0.18-0.35	0.04-0.16
Missouri River	0.14	0.19	0.24	0.13-0.14	0.13-0.24	0.10-0.50
Yellowstone River		0.11	0.12		0.08-0.15	0.05-0.17
Nebraska						
Missouri River	<0.05	0.14	0.11	<0.05-0.07	0.06-0.20	<0.05-0.20
North Platte River		0.11	0.21		0.09-0.14	0.16-0.23
Platte River		0.14	0.14		0.11-0.24	0.11-0.20
South Platte River		0.10	0.23		0.08-0.15	0.11-0.34
North Dakota						
Missouri River	0.19	0.17	0.11	0.13-0.30	0.11-0.24	0.02-0.18
South Dakota						
James River		0.14	0.16		0.08-0.22	0.10-0.22
Utah						
Green River	<0.05	0.18	0.13	<0.05-0.10	0.14-0.24	0.03-0.20
Utah Lake	0.05	0.04	0.01	<0.05-0.06	<0.05-0.07	0.01-0.02

[a] Source: Henderson et al., 1972.

[b] Source: Berger, 1974.

[c] Calculated from author's data.

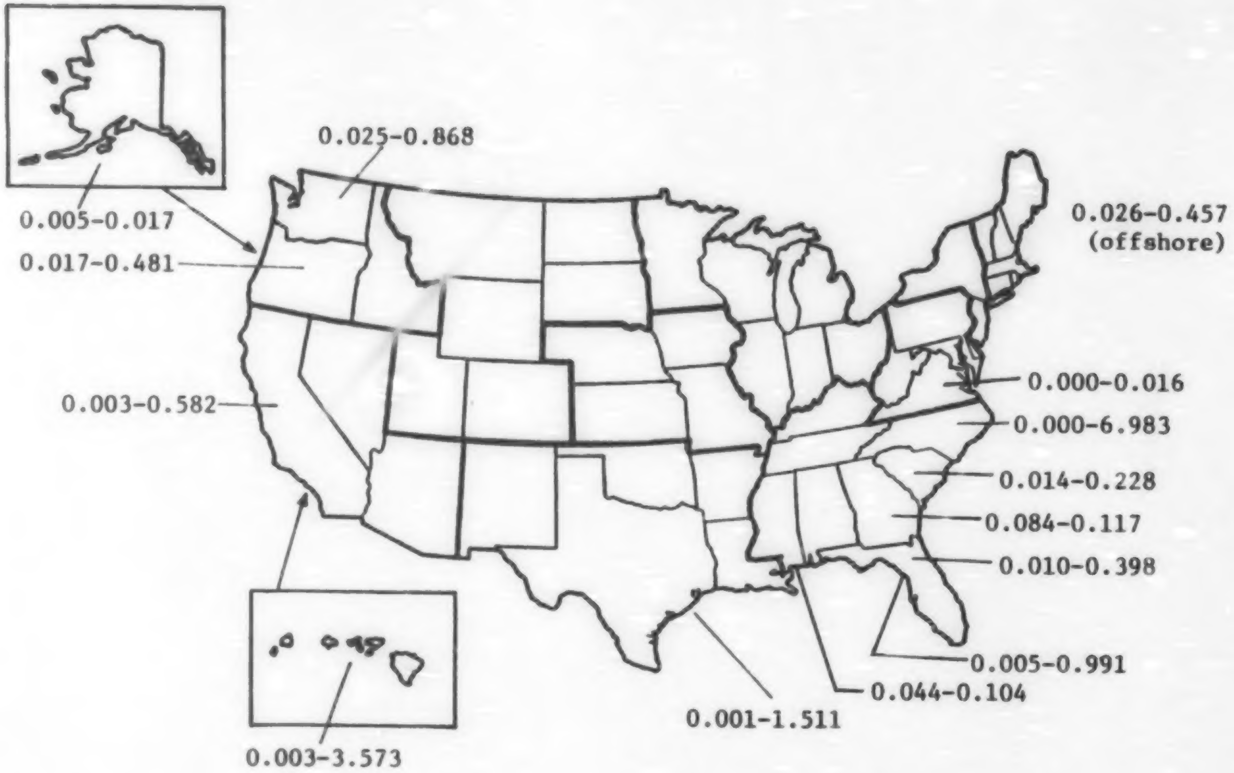
0.025-0.868
0.005-0.017
0.017-0.481
0.003-0.582
0.003-3.573
0.026-0.457
(offshore)
0.000-0.016
0.000-6.983
0.014-0.228
0.084-0.117
0.010-0.398
0.005-0.991
0.044-0.104
0.001-1.511

Figure 2.7. Levels of mercury in fishes, National Marine Fisheries Service Microconstituent Resource Survey (in ppm, wet weight--range of means)(National Marine Fisheries Service, 1975).

snapper. An additional eight species were found to have mean values greater than 0.5 ppm. Highest concentrations were found along the southeastern coast line, particularly along North Carolina and Florida. Elevated values were also found near Galveston Bay, Texas; San Diego, California; Protection Island, Washington; and Hawaii.

Areas of known or suspected mercury contamination have been the sites of many localized investigations of the mercury levels in fish tissue. The most heavily studied include sites of industrial pollution such as the Columbia and Savannah Rivers and the Great Lakes (Buhler et al., 1973; Buhler, 1977; Roberts et al., 1975; Kelso and Frank, 1974; Pillay et al., 1972; Greig and Seagran, 1972) as well as locations where contamination is due to either natural leaching of soils or mining activity, such as in the Columbia and Snake River systems and Lake Powell, Arizona (Blinn et al., 1974; Buhler et al., 1973; Buhler, 1977; Potter et al., 1975). Two states, Ohio and Wisconsin, have been extensively surveyed in comprehensive studies (Stiefel, 1975; Kleinert and DeGurse, 1972).

Incidences of excessive contamination also occurred in Lake St. Clair, Michigan (Greig and Seagran, 1972; Bails, 1972), Lake Erie (Carr et al., 1972; Greig and Seagran, 1972; Pillay et al., 1972; Stiefel, 1975), Lake Michigan (Kleinert, 1972; Kleinert and DeGurse, 1972), and Cranberry Lake in New York (Roberts et al., 1975). Lowest levels found were in fishes from the Great Smokey Mountains in North Carolina, with mean values less than 0.05 ppm (Huckabee et al., 1974; Huckabee, 1972).

Consistently elevated levels of mercury reported in localized marine fish studies were found on the Atlantic coast in Massachusetts' offshore waters (Greig et al., 1975) and particularly along the South Carolina-Georgia coastal region (Stickney et al., 1975; Reimold and Shealy, 1976). Elevated concentrations were found in other areas also but usually in a single species, i.e., blue marlin near Hawaii (Rivers et al., 1972; Shultz et al., 1976), spiny dogfish off the coast of Oregon (Childs and Gaffke, 1973, and starry flounder in Puget Sound, Washington (Buhler et al., 1973). Sources of contamination along the Atlantic coast appear to be industrial (Roberts et al., 1975), whereas in Hawaii and Puget Sound the elevated levels are likely due to natural phenomena (Schultz et al., 1976; Buhler, 1977; Buhler et al., 1973).

Although there are wide variations in mercury content among sampling locations, the literature indicates that overall concentrations of mercury found in fish tissue are slightly higher in freshwater fishes. This may be due, in part, to the greater dilution and dispersion capacity of oceans and the far-ranging habits of most large ocean species. There is some evidence favoring these hypotheses in the lower concentrations found in fishes from offshore north Atlantic waters and in the Pacific Northwest (Greig et al., 1975; Buhler, 1977).

Fish in reservoirs contain higher levels than those collected upstream in free-flowing sections of rivers (Gebherds et al., 1971; Buhler, 1977). Apparently, deposition of sediments rich in mercury in reservoirs provides an opportunity for maximum bacterial formation of methylmercury, which is then readily accumulated by fish.

In both the freshwater and marine studies, there is much evidence that mercury accumulates through the aquatic food chain, resulting in highest concentrations in the muscle tissues of those species at the top of the trophic structure, the piscivores (Buhler, 1977; Potter et al., 1975; Roberts et al., 1975; Pillay et al., 1972; Stiefel, 1975; Walter et al., 1973; Gardner et al., 1975; Peterson et al., 1973). There are a few studies where no indication of bioaccumulation was statistically detected (Greig et al., 1975; Knauer and Martin, 1972; Huckabee et al., 1974). However, the study by Knauer and Martin utilized relatively small sample sizes and that by Huckabee et al. investigated an area of extremely low environmental mercury levels.

Mercury concentration increases with fish weight, length, and age (Kelso and Frank, 1974; Mathis and Kevern, 1973; Knight and Herring, 1972; Richins and Risser, 1975; Peterson et al., 1973; U.S. Senate, 1971). Between 61 and 100 percent of the total mercury found in fishes is present as methylmercury (Henderson et al., 1972; Buhler et al., 1973; Huckabee et al., 1974; Gardner et al., 1975; Knauer and Martin, 1972). Tests have confirmed that significant amounts of a single oral dose of methylmercury is demethylated in sea lions (Buhler and Mate, 1977). This process probably occurs in the liver. In addition, if inorganic mercury was released at some other site, it would tend to concentrate primarily in the kidney in the same manner as it does in animals that have been dosed with inorganic mercury.

Shellfish

Highest levels of mercury in shellfish are reported on the Atlantic coast, particularly near offshore Massachusetts and the Brunswick area of Georgia (Roberts et al., 1975). With the exception of isolated elevated values in Lavaca Bay, Texas, the lowest values reported in the literature were found in the Gulf of Mexico (Roberts et al., 1975). At all locations crabs appeared to have the greatest accumulations. This could be due to their omnivorous food habits.

Data from the National Marine Fisheries Services Resource Survey (National Marine Fisheries Service, 1975) report mercury concentrations in samples of 11 species of mollusks and six species of crustacea collected from all coastal U.S. waters. Only two species, brown shrimp and Dungeness crab, had mean mercury levels greater than 0.1 ppm.

Marine Mammals

Highest mercury concentrations reported in marine mammals from a rather limited data base were found on the Pacific coast--San Miguel Island, California (Anas, 1974), and the Oregon coast (Buhler et al., 1975), in seals and sea lions, respectively.

The general literature indicates that various species of marine mammals were capable of accumulating relatively high tissue concentrations of mercury (Buhler et al., 1975). Seals and walrus which do not migrate from the Arctic region generally contain relatively low concentrations of mercury found in some species of marine mammals, such as California sea lions, is a consequence of the animals living and feeding in U.S. and Canadian coastal waters. Mercury concentrations in coastal areas are known to be higher than those in the open ocean (Jonasson and Boule, 1972; Klein and Goldberg, 1970) as a result of natural and man-related mercury contamination of the marine environment.

With the possible exception of the sea lion epizootic in 1970, carnivorous marine mammals consume large quantities of fish and other marine organisms containing significant amounts of methylmercury with no apparent ill effect. The presence of inorganic mercury in the liver of California sea lions and other marine mammals which ingest large amounts of methylmercury suggests that these animals, and perhaps other species as well, may have some enzymic or other system for detoxifying methylmercury by converting it to the inorganic form. Studies by Lee et al. (1977) suggest that a low-molecular-weight protein called methallothionein may play a protective role in the animals by binding significant amounts of the mercury present in tissues.

There is some evidence that mercury is accumulated as much as 500+ times the concentration of seawater by organisms inhabiting the sediment-water interface (Klein and Goldberg, 1970), and that mercury is transferred through benthic food chains by much smaller factors (Williams and Weiss, 1973). However, a study by Stickney et al. (1975) showed no positive correlation between the levels found in invertebrates and those found in predator fishes.

In order to determine or estimate the environmental distribution of mercury in aquatic invertebrates in the U.S., studies utilizing similar organisms and tissues of those specimens from many more locations are necessary.

Aquatic Plants and Plankton

Few studies have been conducted on the levels of mercury in aquatic plants and plankton. The data from a study of Lake Powell, Arizona (Table. 2.27) may be representative of areas of high natural mercury levels in water (Standiford et al., 1973; Potter et al., 1975). These data show higher levels of mercury in submerged aquatic plants than in algae, moss, or periphyton.

A study of salt-marsh grass on the Georgia coast showed that roots of the grasses accumulate levels of mercury as much as an order of magnitude greater than those accumulated by other plant parts (Windom, 1973). Levels found in phytoplankton ofter appear slightly greater than those in zooplankton (Copeland, 1972; Knauer and Martin, 1972). An investigation by

Knauer and Martin (1972) measured the methylmercury fractions of wet weight samples of phytoplankton. Between 12 and 67 percent of the total mercury content was methylmercury.

TABLE 2.27. LEVELS OF MERCURY IN PLANTS
OF LAKE POWELL, ARIZONA

Organism	Organ	Concentration, ppm wet weight	
		Mean	Range
Nonvascular plants			
Algae	Green tissue	0.015	0.008-0.021
Algae, lichen soil crust	Green tissue	0.023	0.014-0.022
Moss	Green tissue	0.016	0.012-0.020
Periphyton, shallow water	Green tissue	0.032	0.021-0.042
Vascular plants			
Cattail, *Typha latifolia*	Leaf and green tissue	0.036	0.025-0.047
Joint-fir, *Ephedra* sp.	Leaf and green tissue	0.025	
Juniper, *Juniperus osteosperma*	Leaf and green tissue	0.018	0.000-0.040
	Stem	0.021	0.019-0.023
Snakeweed, *Gutierrezia microcephala*	Stem	0.090	0.076-0.104
Unidentified grass	Leaf	0.015	0.010-0.020
Unidentified shrub	Stem	0.039	

Source: Standiford et al., 1973.

3. BEHAVIOR IN THE ENVIRONMENT

Mercury enters the environment through vaporization, volatilization, weathering, dissolution, precipitation, and biodegradation. Its environmental movement depends on its oxidation state; the redox potential, temperature, and pH of the environment; solubility; volatility; and the nature of available chemical species with which it forms strong bonds (Krenkel, 1974). Transport and transformation data indicate that all components of the biosphere contain traces of mercury and constitute potential sources of exposure for all biota, including man.

Some of the complexities of the behavior of mercury in the environment include the following characteristics: (1) forms and compounds of mercury in nature, (2) transformation of mercury in nature, (3) the mercury geochemical cycle, and (4) transport of mercury in the food chain. Emphasis in this discussion is on those characteristics that influence its persistence and environmental fate.

TRANSFORMATION IN NATURE

Although mercury exists in nature in its elemental Hg(0), mercurous Hg(I), and mercuric HG(II) oxidation states, it is readily converted from one form to another, depending on conditions, according to the disproportionation reaction, $2Hg(I) \rightleftarrows Hg(0) + Hg(II)$ (Hem, 1970; Jonasson and Boyle, 1971). The stability and solubility of each of these oxidation states is dependent upon the redox potential, the electrical potential (EL)-pH relationship, temperature, and the concentration of major ions in solution.

Four basic reactions are involved in the mercury interconversion cycle (Figure 3.1): (1) conversion of Hg(0) to Hg(II), (2) conversion of inorganic Hg(II) to methylmercury, (3) conversion of phenyl- to methylmercury, and (4) conversion of alkoxyalkyl to Hg(II) or Hg(0) (Jernelöv, 1969; Jonasson and Boyle, 1971). These reactions permit release of mercury to enhance its movement in soil, water, sediment, and biota.

Metallic mercury, Hg(0), is somewhat reactive: it can be oxidized or reduced in the presence or absence, respectively, of oxygen (Hem, 1970). Its water solubility, 0.02 to 0.03 mg/ℓ at 20 C is higher for the metal than for some of its salts (Krenkel, 1974). Metallic mercury has a marked chalcophile character and, in natural systems, forms sulfides, selenides, a telluride, and complex compounds with antimony, arsenic, and sulfur (Jonasson and Boyle, 1971). It is also an oxyphile forming a natural oxide and a number of oxychlorides and complex hydrous chloride sulfates.

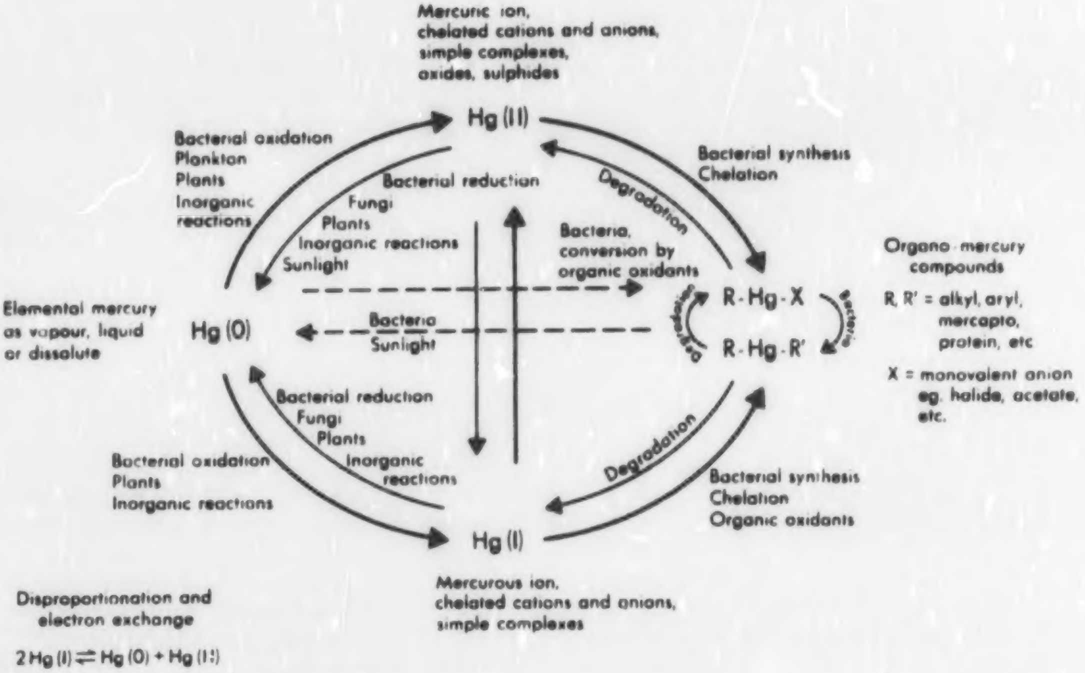
Mercuric ion,
chelated cations and anions,
simple complexes,
oxides, sulphides
Hg (II)
Bacterial oxidation
Plankton
Plants
Inorganic
reactions
Bacterial reduction
Fungi
Plants
Inorganic reactions
Sunlight
Bacterial synthesis
Chelation
Degradation
Bacteria,
conversion by
organic oxidants
Organo-mercury
compounds
R, R' = alkyl, aryl,
mercapto,
protein, etc
X = monovalent anion
eg. halide, acetate,
etc.
Elemental mercury
as vapour, liquid
or dissolute
Hg (0)
Bacteria
Sunlight
R-Hg-X
R-Hg-R'
Degradation
Bacteria
Bacterial reduction
Fungi
Plants
Inorganic
reactions
Bacterial oxidation
Plants
Inorganic reactions
Degradation
Bacterial synthesis
Chelation
Organic oxidants
Hg (I)
Mercurous ion,
chelated cations and anions,
simple complexes
Disproportionation and
electron exchange
2 Hg (I) ⇌ Hg (0) + Hg (II)

Figure 3.1. Cycle of mercury interconversions in nature (Jonasson and Boyle, 1971).

Compounds of Hg(I) are typical of metallic mercury compounds (Krenkel, 1974): (1) all are ionized in solution; (2) most, except for the nitrate and perchlorate, are only sparingly soluble in water at ordinary temperatures; and (3) mercurous chloride (HgCl), the most soluble of the halides, occurs naturally. They are readily oxidized to Hg(II) by strong oxidizing agents. Salts of Hg(I) undergo disproportionation to give Hg(II) derivatives and Hg(0). The mercurous ion, Hg(I), does not form covalent bonds with other elements, and thus organometallic Hg(I) derivatives do not occur.

The mercuric ion, Hg(II), is relatively stable under oxidizing conditions, especially at low pH (Hem, 1970), but can be reduced to Hg(I) or Hg(0) in a reducing environment (Jonasson and Boyle, 1971; Holm and Cox, 1974). When organic materials are present, divalent mercury will also bind to them to form organic complexes.

Mercuric mercury, Hg(II), generally forms covalent rather than ionic bonds, although the nitrate $Hg(NO_3)_2$, sulfate $HgSO_4$, and perchlorate $Hg(ClO_4)_2$ are true salts (Krenkel, 1974). These compounds are less soluble in water than in organic solvents. The Hg(II) cation is not a common species in aqueous media and never constitutes a significant portion of the total mercury found there.

Carbon bonds more stable with Hg(II) than with Hg(I) (Krenkel, 1974). Both mono- and diorganomercury (II) derivatives are well known. Alkylmercuric compounds are more stable and less volatile but are more mobile biologically than other forms of mercury (D'Itri, 1972).

The biological conversion of inorganic mercury to organic methylmercury is the key to the distribution, transport, and bioaccumulation of mercury in the environment (Jensen and Jernelöv, 1969; D'Itri, 1972). In aquatic systems, this conversion occurs by two main processes, microbial (enzymatic) and chemical (nonenzymatic). Enzymatic methylation takes place in organic sediments and in rotting fish (Jensen and Jernelöv, 1969), in cell extracts of methanogenic bacterium (Wood et al., 1968), in cultivated bacterium *Clostridium* (Yamada and Tonomura, 1972), and in fungus *Neurospora* (Landner, 1971). Nonenzymatic synthesis of methylmercury from inorganic divalent mercury occurs under mild reducing conditions with methylcobalamin and propylocobalamin (Wood et al., 1968). Methylmercury is also formed from mercuric chloride by a purely abiotic reaction in the presence of methylcobalamin (Imura et al., 1971; Bertilsson and Neujahr, 1971). However, microbial activity is a prerequisite for methylation in nature unless other methylmetal compounds are already present in the system (Jernelöv and Martin, 1975). Laboratory experiments have shown that mercury methylation also occurs in the terrestrial environment in soils (Berkert et al., 1974; Rogers, 1975) and in the tissues of peas (Gay, 1976).

Rogers (1975, 1976) at the EPA laboratory in Las Vegas has found that the soil transformation of mercury to methylmercury occurs by abiotic as well as biotic means. He determined that a constituent could be extracted from soil which would methylate mercuric ion abioticly. The methylating substance is associated with the lower molecular weight fraction of the soil organic matter. He also found that soil extracts exposed to ultraviolet radiation lose the ability to methylate mercury and that the rate of conversion to methylmercury is dependent upon mercuric ion concentration, solution pH, and temperature.

Pathways which have been proposed for methylation of mercury (Jernelöv, 1969; Wood, 1971; Katz, 1972; Bisogni and Lawrence, 1973; Rogers, 1975, 1976) are summarized in Figure 3.2. Several kinetic schemes have been proposed by Wood (1971), indicating that most anaerobes and many aerobic bacteria can synthesize methylmercury. Under anaerobic conditions, both organic and inorganic mercury compounds are first converted to metallic mercury, then transformed to methylmercury; under aerobic conditions, metallic mercury and organic mercury compounds are converted to mercuric ions before methylation occurs. The formation of methylmercury is predominant at lower pH, while dimethylmercury is favored at higher pH. Monomethylmercury is mainly accumulated in living organisms, while dimethylmercury has a tendency to evaporate to the atmosphere. The released dimethylmercury may break down under ultraviolet light or acidic conditions to monomethyl- or elemental mercury and will precipitate over land or water. Monomethylmercury may convert to dimethylmercury or to volatilizable mercuric ions (Jernelöv, 1972).

The rate of biological methylation of mercury appears to be largely dependent upon the concentration of mercury, the number of methylating organisms, and physical-chemical parameters including pH, temperature, and the presence of oxygen and other organic materials. Fagerström and Jernelöv (1972) found in laboratory experiments that the rate of methylmercury formation in organic sediments is much higher when the oxygen content in water if low, 0 to 2 ppm. The subsequent uptake by fish is also higher at low oxygen levels. In natural waters, a higher rate of methylation can occur under aerobic rather than anaerobic conditions due to the formation of mercuric sulfide (Jernelöv, 1972). Methylation of mercuric sulfide is not likely to occur under anaerobic conditions; even under aerobic conditions, it is 100 to 1000 times slower than with mercuric chloride (Jernelöv and Martin, 1975). The rate of mercury methylation under anaerobic conditions seems to be slow and of less significance ecologically than that under aerobic conditions (Katz, 1972). When sediments are exposed to air by the action of tides or by dredging activities, the rate of methylation is higher by orders of magnitude than the normal rate for sediments under water (Fagerström and Jernelöv, 1972). Bisogni and Lawrence (1972) have found the rate of mercury methylation to be much higher in aerobic systems than in anaerobic systems at a given mercury concentration and microbial growth rate.

Jacobs and Keeney (1974) found a much higher degree of methylation in the sediments of the Wisconsin River with low pH and high organic matter than in the sediments of the Fox River which is characterized by high pH and low organic matter. Temperature also influences the rate (Fagerström and Jernelöv, 1972). The methylation rate increases with temperature, roughly following the Q_{10}-rule (doubled rate when temperature increases 10 C), and with increased nutrient content in the substrate. The rate is also higher with suspended material and in the upper layer of sediment than it is farther down.

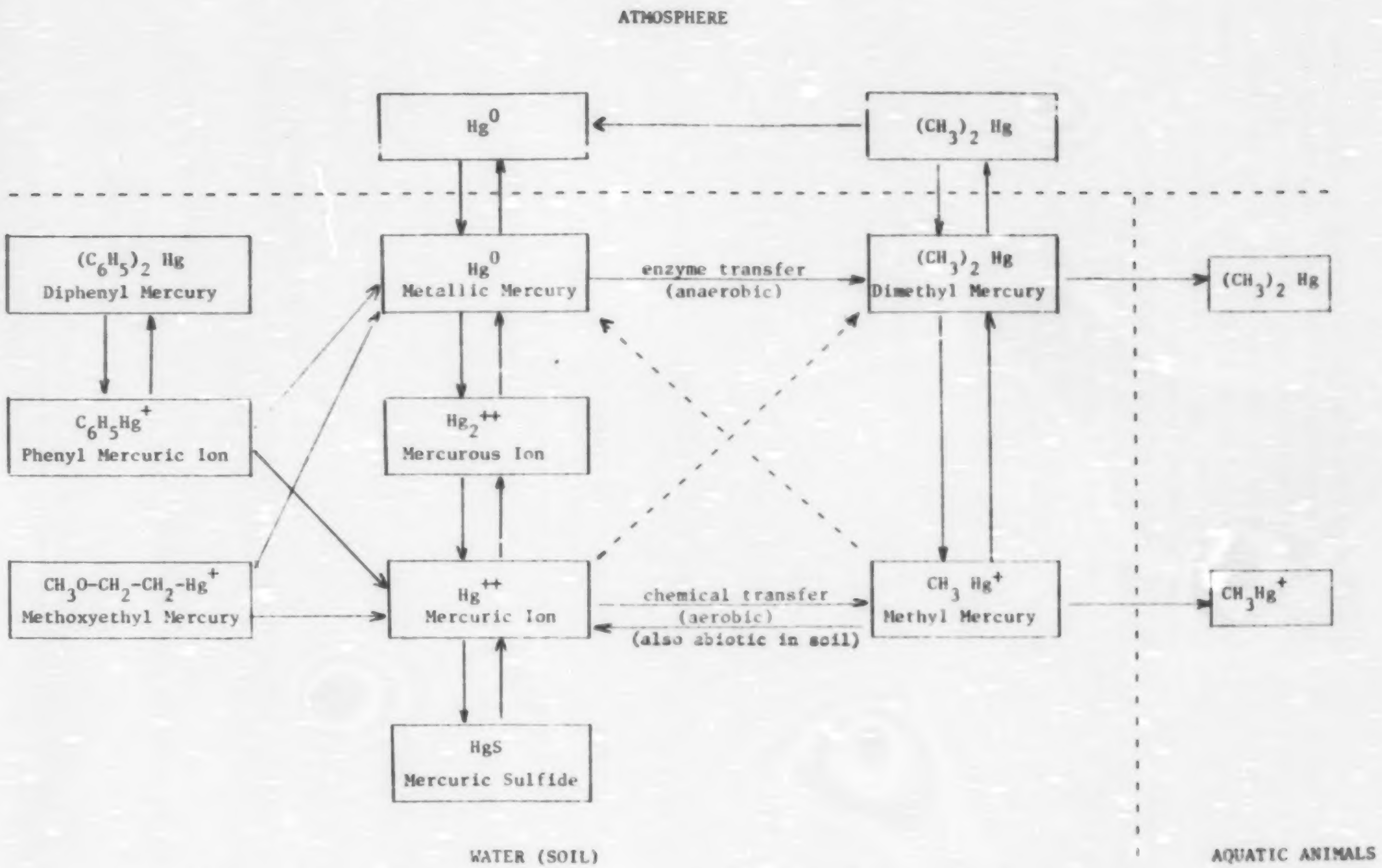
ATMOSPHERE
Hg^0
$(CH_3)_2$ Hg
$(C_6H_5)_2$ Hg
Diphenyl Mercury
Hg^0
Metallic Mercury
enzyme transfer
(anaerobic)
$(CH_3)_2$ Hg
Dimethyl Mercury
$(CH_3)_2$ Hg
$C_6H_5Hg^+$
Phenyl Mercuric Ion
Hg_2^{++}
Mercurous Ion
$CH_3O-CH_2-CH_2-Hg^+$
Methoxyethyl Mercury
Hg^{++}
Mercuric Ion
chemical transfer
(aerobic)
(also abiotic in soil)
CH_3 Hg^+
Methyl Mercury
CH_3Hg^+
HgS
Mercuric Sulfide
WATER (SOIL)
AQUATIC ANIMALS

Figure 3.2. Pathways of mercurial breakdown and methylation in nature (Jernelöv, 1969; Wood, 1971; Katz, 1972; Bisogni and Lawrence, 1973; Rogers, 1975 and 1976).

Matsumura et al. (1971) found that microorganisms isolated from mercury-containing soil and lake sediments convert phenylmercuric acetate to diphenylmercury but observed no methylmercury derivatives after 10-day incubations. During long-term, 50 days, incubation of lake sediments containing inorganic mercury, Spangler et al. (1973) observed a buildup of low concentrations of methylmercury, up to 0.3 μg/g sediment. There was a rapid decrease in the amount of methylmercury due to microbial degradation followed by the evolution of elemental mercury, suggesting that the net amount of methylmercury accumulation in the sediment would be minimal. Degradation of methylmercury has been observed in cultures of bacteria Pseudomonas (Tonomura et al., 1968), in rats (Norseth and Clarkson, 1970), and in the guinea pig (Iverson and Hierlihy, 1974).

GEOCHEMICAL CYCLE OF MERCURY

The processes by which mercury is transportated through the geochemical cycle are shown in Figure 3.3 (Jonasson and Boyle, 1971). Because of its high vapor pressure, even at normal temperatures, elemental mercury rapidly vaporizes from rocks, soils, and waters into the atmosphere. At room temperature, the saturation concentration of mercury in air approaches 15 mg/m^3 (Vostal, 1972). Mercury is also released to the atmosphere by volatilization, chemical or microbial reduction, and biological methylation.

Solubility is a major factor in the natural distribution of mercury. Practically all mercury in air disappears immediately after a rainstorm, even in areas of higher concentration such as near ore deposits (McCarthy et al., 1970). Despite a tendency to sorb on soil, plants, or animals or to complex with other organic materials and minerals, mercury compounds are translocated within the soil or into the hydrosphere by surface runoff, groundwater, or geothermal springs. Weathering and sedimentation are the major pathways for the natural flux of mercury between land and the oceans.

The summation of available data on the global cycling of mercury from natural and man-made sources indicate that the total release of mercury in nature due to weathering and vaporization amounts to 20,000 to 40,000 metric tons per year, while man's activitiy contributes an additional 5,000 to 10,000 metric tons per year (Table 3.1) (Hammond, 1971; Dickson, 1972; Wollast et al., 1975). While these data may be open to question, they suggest that man's activity could increase the natural flux by up to 60 percent.

The residence times of mercury in the four available reservoirs (Wollast et al., 1975) are reported as:

Reservoir	Time
Land	1,000 years
Atmosphere	60 days
Ocean	32,000 years
Sediments	2.5×10^8 years

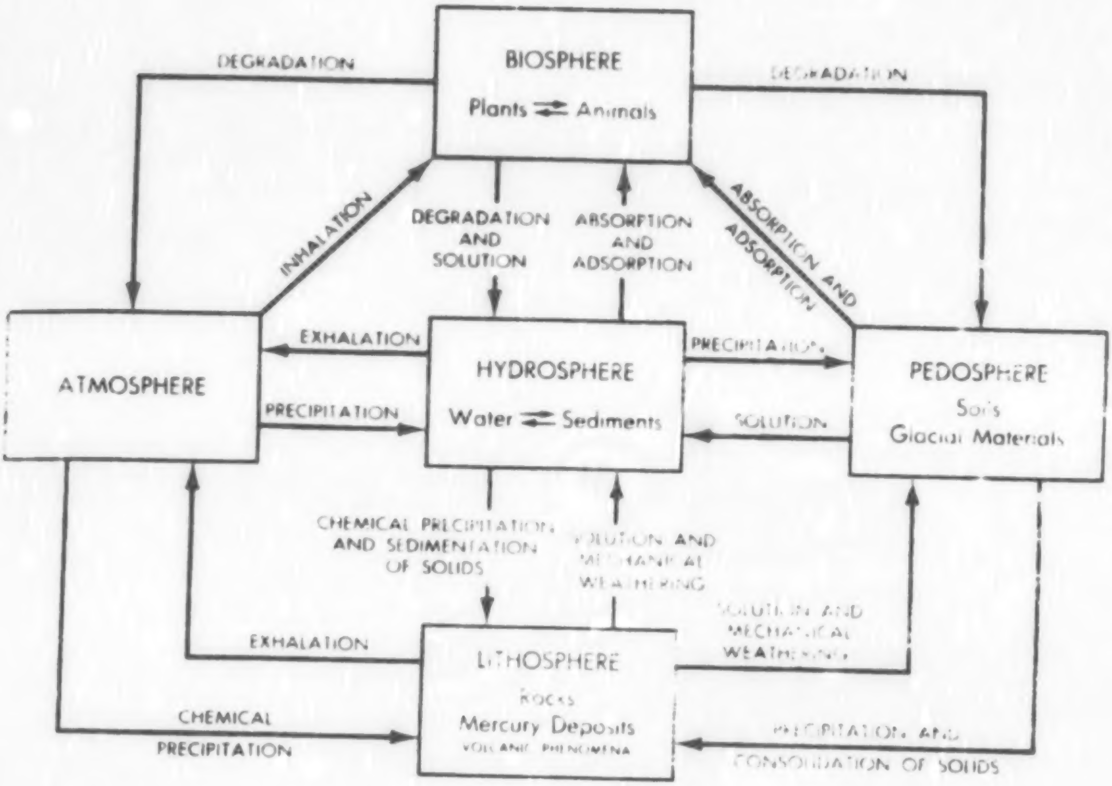
DEGRADATION
BIOSPHERE
Plants ⇄ Animals
DEGRADATION
INHALATION
DEGRADATION AND SOLUTION
ABSORPTION AND ADSORPTION
ABSORPTION AND ADSORPTION
ATMOSPHERE
EXHALATION
HYDROSPHERE
Water ⇄ Sediments
PRECIPITATION
PEDOSPHERE
Soils
Glacial Materials
PRECIPITATION
SOLUTION
CHEMICAL PRECIPITATION AND SEDIMENTATION OF SOLIDS
SOLUTION AND MECHANICAL WEATHERING
SOLUTION AND MECHANICAL WEATHERING
EXHALATION
LITHOSPHERE
Rocks
Mercury Deposits
VOLCANIC PHENOMENA
CHEMICAL PRECIPITATION
PRECIPITATION AND CONSOLIDATION OF SOLIDS

Figure 3.3. Generalized geochemical cycle of mercury in natural systems (Jonasson and Boyle, 1971).

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TABLE 3.1. GLOBAL CYCLING OF MERCURY
(metric tons/year)

Natural Flux		Man's Activity			
Weathering	Vaporization	Industrial Wastes	Fossil Fuel Combustion (Coal and Oil)	Total Flux	Reference
230	NA[a]	3,000	3,000[b]		Joensuu, 1971
3,800	>25,000	5,800	1,600	36,000	Weiss et al., 1971
2,500	NA	NA	1,600		Bertine and Goldberg, 1971
4,000	36,000	NA	3,000-5,000	43,000-45,000	Marton and Marton, 1972
5,000	25,000	5,000	5,000	40,000	Wollast et al., 1975

[a] NA = Not available.

[b] Coal only.

The tentative present-day geochemical cycle of mercury in the biosphere is shown in Figure 3.4.

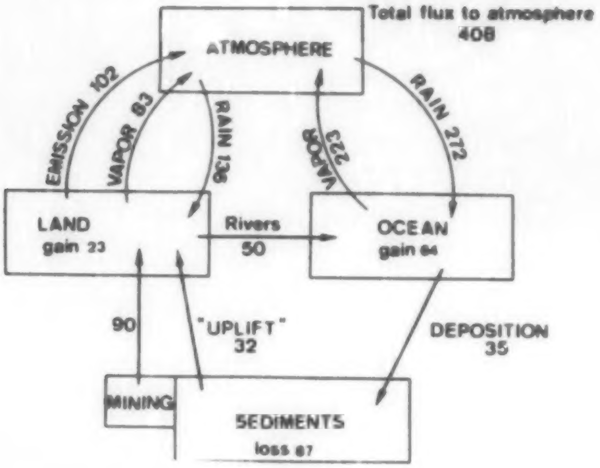

Figure 3.4. Tentative present-day cycle of mercury (reservoir changes and fluxes in units of 10^2 MT/yr). [Reprinted from Ecological Toxicology Research (A. D. McIntyre and C. F. Mills, editors) by R. Wollast, G. Billen, and F. T. Mackenzie by permission of Plenum Publishing Corporation. Year of publication 1975.]

Air Transport

Mercury is readily emitted to the atmosphere due largely to its volatility and high vapor pressure. Presumably, in the U.S., over 500 metric tons of mercury are emitted to the atmosphere each year from man's activity (Holt et al., 1975). Mercury and its compounds are dispersed in air by wind and are deposited on land and water by dry precipitation, rainfall, and snowfall. However, the mode of transport and fate of this pollutant are not clearly understood.

The ambient forms of mercury in air include particulates, mercuric chloride-type compounds, methylmercury (II-type compounds), elemental mercury, and dimethylmercury (Braman and Johnson, 1975). Vapors tend to concentrate by adsorption on dust particles (Williston, 1968) and, together with the other particulates, are removed by dry fallout, rain, and snowfall (Jenne, 1970). The saturation concentration of mercury in air amounts to 10 to 15 mg Hg/m^3 at room temperature (Vostal, 1972).

While the rate of mercury release into the atmosphere is determined mainly by barometric pressure, its distribution and transport are largely controlled by wind, rainfall, and snowfall, seasonal variations in temperature, and other natural and meteorological laws (McCarthy et al., 1970). Williston (1968) found higher, nearly double, mercury concentrations in summer than in winter in the San Francisco Bay area. Diurnal variations have also been observed (McCarthy et al., 1970). Generally, the greatest amounts are found at midday, while minimum concentrations are observed in the morning and evening when the rate of increase in barometric pressure is high. Higher mercury readings have been observed on cloudy and foggy days than on normal days, yet no clear correlation has been found between humidity and mercury content of the air. Elevated atmospheric concentrations of mercury also have been observed on smoggy days (Krenkel and Goldwater, 1973; Williston, 1968). Cool, wet weather generally results in lower than average mercury readings, whereas the reverse is true for warm, dry weather. However, the daily maximum mercury reading does not necessarily coincide with the daily maximum temperature (McCarthy et al., 1970).

More mercury is found in the air of mercury mines and mineral deposits than elsewhere (McCarthy et al., 1970). However, the dependence of mercury content on the distance from a source is more likely a function of mercury species and the prevailing wind. In studies around sewage plants in Washington, D.C., and Memphis, Tennessee, the concentration of elemental mercury in air decreased sharply with increasing distance from the source, while the organic mercury forms increased almost logarithmically with distance up to at least 16 km (10 mi) (Soldano et al., 1975). This suggests that the alkylmercury compounds can be spread over a broad area and long distance from the source, a phenomenon which is enhanced by the prevailing wind direction and velocity in the area (Anderson and Smith, 1977).

The vertical distribution of mercury in air appears also to be a function of altitude (McCarthy et al., 1970). Maximum levels above the soil surface near mercury mine areas are reportedly nearly 200 times greater than those found at 122 m (400 ft) above the ground (Table 3.2). This altitude effect is much less significant in nonpolluted areas and varies according to seasonal/temperature differences (Williston, 1968). Williston (1968) suggests that mercury is uniformly distributed in soil throughout the United States by wind action as well as by rainfall and snowfall.

Soil Transport

The mercury concentration of soil varies significantly at different locations. In addition to the naturally occurring mineral deposits, large quantities may be deposited from the atmosphere and a lesser amount may be added by agricultural applications such as pesticides and seed treatments.

Factors influencing the mercury content of soils include pH, drainage composition, concentrations of humus, and microbial activity. Mercury compounds may convert to soluble or volatile forms by geochemical and biological actions within the soil. Metallic mercury may be readily volatilized or converted to mercuric sulfide or, due to its high affinity for organic matter, to organic mercury compounds. Thus, the accumulation of mercury in soil may be related to the total sulfide and organic carbon levels (Lagerwerff, 1972).

TABLE 3.2 MAXIMUM MERCURY CONCENTRATION IN AIR MEASURED AT SCATTERED MINERALIZED AND NONMINERALIZED AREAS OF THE WESTERN UNITED STATES

Sample Location	Maximum Concentration, ng/m^3 Ground Surface	122 m (400 ft) above ground
Mercury Mines		
Ord mine, Mazatzal Mtns., Arizona	20,000 (50)[b]	108 (4)
Silver Cloud mine, Battle Mtn., Nevada	2,000 (50)	24 (8)
Dome Rock Mtns., Arizona	128 (6)	57 (20)
Base and Precious Metal Mines		
Cerro Colorado Mtns., Arizona	1,500 (5)	24 (2)
Cortez gold mine, Crescent Valley, Nevada	180 (60)	55 (4)
Coeur d'Alene mining district, Wallace, Idaho	68 (40)	NA[c]
San Xavier, Arizona	NA	25 (3)
Porphyry Copper Mines		
Silver Bell mine, Arizona	NA	53 (3)
Esperanza mine, Arizona	NA	32 (3)
Vekol Mtns., Arizona	NA	32 (4)
Ajo mine, Arizona	NA	30 (3)
Mission mine, Arizona	NA	24 (3)
Twin Buttes mine, Arizona	20	22 (3)
Pima mine, Arizona	NA	13 (3)
Safford, Arizona	NA	7 (2)
Unmineralized Areas		
Blythe, California	NA	9 (20)
Gila Bend, California	NA	4 (2)
Salton Sea, California	NA	3.5 (2)
Arivaca, Arizona	NA	3 (2)

Source: McCarthy et al., 1970.

[a] Samples taken from single-engine aircraft.

[b] Number of measurements shown in parenthesis.

[c] NA - Not available.

A linear relationship exists between humic acid and mercury content in soil (Trost and Bisque, 1972). Humus-rich soil also increases the solubility of inorganic mercury compounds, such as mercuric sulfide, mercuric oxide, and mercurous chloride, above their normal levels. Over 1,000 ng of mercury have reportedly been absorbed on 1 g of organic matter in soil (Andersson, 1967; Eriksson, 1967). This reaction is enhanced at lower pH.

Moisture affects the vaporization of mercury compounds at the soil surface; vaporization decreases with increasing soil moisture (Williston, 1968; Kimura and Miller, 1964).

Although they are more chemically stable, methylmercury compounds are not bound as firmly to soil or other organic mercury compositions. Aryl and alkoxyalkyl mercury salts decompose more readily in soil and liberate ionic and/or metallic mercury (Rissanen and Miettinen, 1972). Up to 16 percent of phenylmercury acetate and 32 percent of ethylmercury acetate may volatilize as metallic mercury vapor in 28 days and 53 days, respectively (Kimura and Miller, 1964). Methyl derivatives are volatilized as methylmercury at a rate of 6 to 14 percent in 35 days without decomposing to metallic mercury vapor. From 51 to 53 percent of methylmercury dicyaniamide added to soil may be retained after 5 months (Saha et al., 1970).

In microcosms, 139 days after the application of ^{203}Hg, Huckabee and Blaylock (1974) reported that 50 percent of the total ^{203}Hg remained in the terrestrial system and 50 percent reached the aquatic system. About 90 to 97 percent of the mercury in the terrestrial system was bound to the soil; only 3 to 7 percent was retained on the litter and less than 1 percent absorbed by plants. Old field ecosystem studies have indicated that nearly 80 percent of ^{203}Hg applied to soil is retained at the end of the growing season (4 months) (Matti et al., 1975). The amount of mercury increases with time, and more than 90 percent is confined in the top 3 cm of the column. Levels of mercury in plants bear little relationship to soil levels since most plants grown in mercury-treated soils accumulate such small amounts (Smart, 1968; Blanton et al., 1975).

Water and Sediment Transport

Much of the mercury entering surface waters is rapidly adsorbed or bound to suspended materials and living organisms (Jenne, 1970). Acidity is important for the degree of binding. Mercury solutes introduced into streams are quickly transformed to particulates by reduction to metallic mercury, sorption onto inorganic sorbates, complexation with nonviable particulate organics, and sorption and ingestion by biota. The majority of all forms of mercury in water accumulate in the bottom sediment (Vostal, 1972). In groundwaters, the bicarbonate content is directly related to mercury concentration (Jenne, 1970).

The mobility of mercury in water is mainly determined by the presence and amount of organic materials and suspended sediments and the occurrence of redox conditions (Jenne, 1970). Elevated levels of dissolved organic materials may increase mercury mobility. A high percentage of mercury introduced into streams is removed as sediment and associated fine-grained materials. Reducing conditions may increase mercury mobility by causing the dissolution of manganese and iron oxides and by releasing sorbed mercury to be available for complexing with other organics; they may also decrease mercury mobility by reducing a significant amount of mercury compounds to metallic mercury which will then amalgamate with iron oxides or fall to the bottom. Mercury becomes relatively immobile in reducing sediments and precipitates as mercuric sulfide (cinnabar). However, at high pH or under strongly reducing conditions, mercuric sulfide anions may become very soluble.

Chlorides may also affect the release of mercury from bottom sediments. The use of $CaCl_2$ and NaCl for deicing roads increases the relative amount of mercury in water in equilibrium with sediments by 2 to 5 orders of magnitude (Feick et al., 1972). The changes in pH associated with the addition of these salts may increase mercury mobility.

The transport and deposition of mercury in estuaries is largely governed by interactions with natural organic matter (Lindberg and Harris, 1974). In the estuaries of the Gulf of Mexico, approximately 54 to 82 percent of the total dissolved mercury is associated with fulvic acid-type materials. Decomposition of estuarine vegetation results in detritus enriched in mercury. Thus, in the Gulf of Mexico, mercury in estuarine sediments is not significantly redistributed by postdepositional processes.

Windom (1976) reported that only 14 percent, 0.5×10^3 kg/yr, of the mercury transported by several southeastern U.S. rivers is in particulates, while the majority, 2.7×10^3 kg/yr, is in soluble form. However, more than 95 percent of the total mercury in the Walker Branch streams in Tennessee is in suspended forms. The contribution to total transport of mercury by suspended sediments is approximately 45 percent, while about 55 percent is due to dissolved mercury (Andren et al., 1975).

Up to 62 percent of the mercury present in surface sediments is bound to sulfur-containing organic and inorganic particles, clays, and minerals (Stopford and Goldwater, 1975). In deeper sediments, more mercury, up to 75 percent, is bound to organic acids. Only a small portion of this mercury is released to water. Simulated dredging results in a slight increase in the total dissolved mercury in overlying water because of the mixing of sediment with water and short-term release of the mercury associated with particulate materials (Lindberg and Harris, 1974).

Sedimented mercury can be released by biological methylation processes. Methylated mercury is quickly absorbed by living organisms or bound to inorganic suspended particulates, or it may be rapidly photodegraded to inorganic mercury and escape to air. Therefore, methylation processes facilitate mercury transport not only by releasing mercury from sediments to water and air but also by movement within the food chain. However, they may not play a major role in the postdepositional migration of mercury in sediments (Andren and Harris, 1973). Stopford and Goldwater (1975) and Windom et al. (1976) found little or no methylmercury in the sediments.

Although Windom et al. (1976) detected a significant level of methylmercury in the dominant primary consumers of the estuarine ecosystem, the estimated annual methylmercury conversion was only about 50 ng/g of the total mercury in the upper 5 cm of the sediment column. This indicates that methylation is an inefficient mechanism for transferring mercury out of salt marsh sediments. Methylation of mercury is entirely restricted to the surface of the sediment with no macrofauna present (Jernelöv, 1970). If sediment-dwelling organisms are present at high densities, the release of mercury by methylation may occur in sediment at depths to 9 cm.

A study of the mechanisms for mercury transformations affecting mobility in Par Pond at the Savannah River in Georgia has shown that the reduction of mercury to its elemental form within a sedimentary environment is accomplished by humic acids serving as an extracellular electron transport mechanism (Schindler et al., 1975). The mercury not liberated from sediments by this mechanism is retained by the organic macromolecules and alkylated to methylmercury. This mechanism, however, accounts for only a small portion of the mercury in the system. The electron transport capacity of the organic ligands may be blocked by calcium, clays, or other cations and effectively suppress the alkylation/reduction potential of the sediment.

FOOD CHAIN TRANSPORT

Most aquatic organisms can accumulate mercury in their tissue. Concentration factors of mercury in edible aquatic organisms are 3 to 5 orders of magnitude greater than background levels (Thompson et al., 1972) (Table 3.3). The concentration by plants and fish appears to be at the same level of magnification, but uptake by aquatic invertebrates is much greater, reaching up to 100,000 times the surrounding water level. Since invertebrates are not at the top of the food chain, it can be assumed that the biological magnification of mercury could be a function of the particular species in the trophic level. However, the levels of mercury in general increase with increasing trophic level (Table 3.4). Mean mercury levels in predators are nearly 15 times greater than those in algae eaters. Aquatic organisms accumulate mercury compounds directly from ambient water and from their food. They absorb both inorganic and organic methylmercury compounds.

Neither uptake routes nor the relative importance of mercurials in food chain accumulation and transport have been fully quantified. The fact that methylmercury compounds are the predominant form of mercury in aquatic organisms even though methylmercurials are never found in abundance in water indicates that mercury in aquatic organisms is accumulated mainly through the food chain (Huckabee and Goldstein, 1975). A series of laboratory experiments has shown that methylmercurials have a higher assimilation efficiency and longer biological half-life than inorganic and other organic forms of mercury. Species differences in biological half-lives of methylmercury exist even within various fish species living in the same environment (Vostal, 1972). The rate of mercury uptake through the food chain is higher in the top predator fish (60 percent for pike)

TABLE 3.3. CONCENTRATIONS (IN PPM WET WEIGHT) AND CONCENTRATION FACTORS OF MERCURY IN WATER AND EDIBLE AQUATIC ORGANISMS

Media	Mercury Concentration	Concentration Factor
Sea water[b]	3.0×10^{-5}	
Marine plants[c]	3.0×10^{-2}	1.0×10^{3}
Marine invertebrates[d]	1.0×10^{0}	3.3×10^{4}
Marine fish[e]	5.0×10^{-2}	1.7×10^{3}
Freshwater	1.0×10^{-4}	
Freshwater plants	1.0×10^{-1}	1.0×10^{3}
Freshwater invertebrates	1.0×10^{1}	1.0×10^{5}
Freshwater fish	1.0×10^{-1}	1.0×10^{3}

Source: Thompson et al., 1972.

[a] Concentrations in edible portions, e.g., muscle and soft parts; concentration factor determined by dividing the concentration in the organixm by the concentration in water.

[b] Representative values for the continental shelf and estuaries, not for open ocean.

[c] Exclusive of phytoplankton.

[d] Molluscs and crustaceans.

[e] Edible portion only, not whole fish.

TABLE 3.4. BIOLOGICAL MAGNIFICATION OF MERCURY IN THE AQUATIC FOOD CHAIN

Organisms	Number of Samples	Concentration, ppm		More Numerous Organisms
		Range	Arithmetic Mean	
Algae eaters	39	0.01-01.8	0.05	Zooplankton, snails, mayfly nymphs
Zooplankton eaters	9	0.01-0.07	0.04	Insect larvae, minnows
Omnivores	9	0.04-1.16	0.45	Insect larvae and adults, scuds
Detritus eaters	12	0.13-0.59	0.54	Worms, clams, insect larvae
Predators	25	0.01-5.82	0.73	Insect larvae and adults, frogs

Source: Bligh, 1971.

and relatively lower for bottom feeders (less than 25 percent) (Jernelöv and Lann, 1971). Thus it appears that direct uptake of mercury from water is more important in lower trophic level organisms, while the food chain is the main route of uptake in higher level organisms. Direct accumulation of mercury compounds from water is similar for both feeder types.

Information on the mercury content of aquatic organisms is extensive, but the vast majority of the data are presented as total mercury instead of as the methylmercury form. Information needed to clarify the actual food chain transport mechanism for mercury is therefore greatly impaired.

Bioaccumulation through the terrestrial food chain appears to be less significant to man than the aquatic food chain since the main route is dressed seed → game birds → man (Rissanen and Miettinen, 1972). Other terrestrial routes are much less obvious and require further study.

4. OCCURRENCE OF MERCURY IN FOOD

MERCURY LEVELS IN FISH

The major dietary source of mercury for many humans is fish and shellfish. Birke et al. (1972) concluded from a study of human exposure to methylmercury through fish consumption that this source contributes at least half of the mercury intake among fish eaters. Mercury concentrations in blood cells were approximately twice the concentration found in the blood of persons who did not eat fish, further confirming the importance of fish consumption as a critical determinant of mercury intake. Per capita fish consumption in the United States averages only 18 g per day; comparable values for Swedes and Japanese are 56 and 88 g per day, respectively (Hugunin and Bradley, 1975).

Following the Canadian Food and Drug Administration's closure of Lake St. Clair (an international boundary lake) to commercial fishing in March, 1970, and subsequent discovery that game fish in Lake St. Clair, Michigan, had up to 7.0 ppm mercury and in Lake Champlain, Vermont, up to 2.5 ppm, the U.S. Food and Drug Administration Compliance Program was initiated (Schroeder, 1974). Serious mercury contamination was found in 25 rivers and bays in 11 states. Of 763 composite samples of fish, nearly 90 percent showed mercury levels below 0.5 ppm. The highest mercury levels were consistently observed in tuna.

To determine the extent of the problem, the entire canned tuna supply of the United States was analyzed (Kolbye, 1972). Results disclosed that less than 4 percent of the tuna examined exceeded FDA's administrative guideline for 0.5 ppm mercury. A similar sampling program for swordfish revealed that less than 5 percent of the swordfish samples were within the 0.5 ppm guideline and 53 percent exceeded 1 ppm (Clark, 1973). In May, 1971, a public warning was issued against the consumption of swordfish. Since 1971, all swordfish offered for sale in the United States are examined for mercury and sold only after individual fish certification (Kolbye, 1972).

In 1971, FDA also conducted an extensive analysis program of the 19 most commercially important fish. The mean mercury level in saltwater fish was approximately 0.09 ppm; however, mercury concentration in a number of fish of certain species, such as snapper, bonito, and mackerel, were above the 0.5 ppm level. Seizure or recall actions were initiated against 14 lots of snapper and 3 lots each of bonito and mackerel out of over 1,000 lots examined. Other predatory fish have been implicated also but not in commercially significant quantities (Kolbye, 1972).

Swedish studies have indicated that fish caught in inland waterways and coastal waters often have much higher levels of mercury than deep sea fish, suggesting the etiologic role of mercury-containing industrial effluents in causing excessive mercury uptake in fish from these waters (Hugunin and Bradley, 1975). Although average levels of mercury in fish seem difficult to assess, the most significant sources of variation relate to species, diet, age, size, metabolic rate, and habitat (Hugunin and Bradley, 1975). Table 4.1 represents a condensation of data presented by Peyton et al. (1975) grouping fish according to nominal mercury content.

Examining the mercury content of commercial canned shrimp, oysters, clams, salmon, tuna, anchovies, cat food, and others, Hall (1974) obtained values for "percent methylmercury" that are in general agreement with those of several similar studies reported in the literature reviews by Hugunin and Bradley (1975) and D'Itri (1972) (Table 4.2).

In a study of fish from waters of the southeastern United States which were suspected of being polluted by the chlor-alkali industry, Granade (1972) concluded that a serious mercury problem exists in this area and that mercury poisoning could result from a consistent diet of fish caught from certain parts of the rivers. The mercury levels reported by Granade (1972) include the highest values reported in Table 4.3. Follow-up studies are not available to evaluate the degree to which pollution continues in these systems.

Henderson and Shanks (1973), reporting the results of a nationwide monitoring program conducted by the U.S. Bureau of Sport Fisheries as part of the National Pesticides Monitoring Program, found the highest residues were reported in fish from the Columbia, Snake, Salmon, Rouge, and Truckee rivers; the lowest levels were in fish from Alaskan streams and the Colorado River (Table 4.3). Eleven samples exceeded the FDA action level of 0.05 ppm; however, this is significant only in those fish destined for human consumption. Not all the species sampled in this program would normally be eaten (Henderson and Shanks, 1973). Van Meter (1974), focusing on the evaluation of concentrations of mercury in muscle tissue of game fish, studied the "effective" measure of exposure in terms of human dietary dosage. He reported that tissue concentrations of mercury were low in fish from most of the Upper Clark Fork River region of Montana, an area noted for diverse mining operations. Consistently higher mercury levels were found in fish taken from Flint Creek which is fed by several tributaries from a mining district (Table 4.3).

MERCURY LEVELS IN FOODS EXCLUDING FISH

Although the high levels of mercury in fish and seafoods indicate that these sources potentially contribute a majority of mercury intake, examination of mercury levels in nonfish commodities is important because:

(1) Fish and shellfish represent a relatively insignificant portion of the average American diet.

TABLE 4.1. SUMMARIZATION OF FISH TYPE BY TOTAL MERCURY CONTENT (IN PPM)

0-0.10	0.11-0.25	0.26-0.45	0.46-0.65	0.66-0.99	1.00-1.70	5.5
Bloater	Bluegill	Drum	Eel	Muskellunge	Crevelle jack	Blue marlin
Crayfish	Buffalo	N. pike	Bluefish	N. squawfish	Grouper	
Chub	Bullhead	Perch	Dogfish shark	Pickerel	Ocean catfish	
Hatchery trout	Carp	Sanger	Gag	Walleye	Swordfish	
L. whitefish	Catfish	Sheephead	Lingcod	Redfish		
Salmon	Crappie	Sucker	Mullett	S. mackerel		
Shiner	Coho salmon	Whitebass	Sea catfish			
Crab	Goldeye	Bonita	Sea trout			
Clam	Goldfish	Croaker	White marlin			
King crab	Gar	K. mackerel				
Lobster tail	Pumpkinseed	Menhaden				
Oyster	River carp	Pompano				
Scallops	Rockbars	Red snapper				
Shrimp	Shad	Sablefish				
Other shellfish	S. mullett	Tuna				
Alewife	Sturgeon	Bass				
Anchovies	Sunfish					
Butterfish	Trout					
Cod	D. crab					
Fish sticks	Lobster					
Haddock	Dolphin					
Herring	Halibut					
J. mackerel	Pollock					
Ling	Rockfish					
Ocean perch	Scup porgy					
Salmon						
Sardines						
Seafood plate						
Smelt						
TV dinners						
Whitefish						
Whiting						
Flounder						

Source: Peyton et al., 1975.

TABLE 4.2. MERCURY RESIDUES IN CANNED SEA FOOD

Sample	Product	Methylmercury, ppm[d]	Total Mercury, ppm[e]	Methylmercury, %
1	Shrimp	0.007	0.009	78
2	Oysters	0.020	0.037	54
3	Oysters	0.027	0.033	82
4	Minced clams	0.029	0.046	63
5		0.088	0.047	187
6	Clam sauce	0.012	0.033	36
7[a]	Cat food	0.019	0.035	54
8[a]		0.015	0.039	38
9	Sardines	0.021	0.038	55
10	Anchovies	0.090	0.21	43
11	Kippered herring	0.081	0.13	62
12	Pink salmon	0.009	0.016	56
13		0.023	0.064	36
14		0.015	0.020	75
15	Red sockeye salmon	0.045	0.047	96
16	Coho red salmon	0.025	0.018	139
17[b]	White tuna	0.31	0.38	82
18		0.20	0.24	83
19		0.25	0.39	64
20		0.32	0.38	84
21		0.22	0.20	110
22		0.34	0.43	79
23[c]	Tuna	0.28	0.36	78
24[c]		0.35	0.39	90
25	Light tuna	0.68	0.73	93
26		0.50	0.57	88
27		0.31	0.45	69
28		0.25	0.21	119
29		0.53	0.60	88
30		0.33	0.43	88
31		0.23	0.24	77
32		0.40	0.55	96
33		0.15	0.13	73
34		0.29	0.26	115
35		0.18	0.20	112
36		0.29	0.33	90

Source: Hall, 1974.

[a] Samples 7 and 8 had the same lot number.
[b] Average percent methylmercury in tuna Samples 17-36 = 89 percent.
[c] Samples 23 and 24 had the same lot number. Both cans were unlabeled.
[d] Determined by gas-liquid chromatography.
[e] Determined by atomic absorption spectrometry.

TABLE 4.3. MERCURY CONTENT OF SELECTED FOOD FISH

Location	Date	Organism	Sample Site	Concentration, ppm Mean	Concentration, ppm Range	Reference
Region 1						
Pacific and Alaska	1969	Fish	Composite	0.25	0.06-1.25	Henderson and Shanks, 1973
	1970	Fish	Composite	0.26	0.05-1.7	
Region 2 Southwest	1969	Fish	Composite	0.08	<0.05-0.14	
Region 3 North Central	1969	Fish	Composite	0.20	<0.05-0.50	
Region 4 Southeast	1969	Fish	Composite	0.23	<0.05-1.0	
Region 5 Northeast	1969	Fish	Composite	0.23	<0.05-0.80	
Alabama	1970	Fish	Composite	0.36	0.01-2.26	Granade, 1972
Florida	1970	Crabmeat		0.39	0.33-0.50	
Georgia	1970	Fish	Composite	0.40	0.0-1.70	
Kentucky Murray area	NA	Unspecified, cooked	Muscle	0.375		Dassani et al., 1975
Montana						
Ninemile Creek	NA	Trout	Muscle	0.15	NA	Van Meter, 1974
	NA	Whitefish	Muscle	0.17	NA	
Clark Fork River	NA	Shiner	Muscle	0.13	NA	
	NA	Sucker	Muscle	0.27	NA	
	NA	Squawfish	Muscle	0.25	NA	
Flint Creek	NA	Brown trout	Muscle	0.53	ND	
Rattlesnake Creek	NA	Sculpin	Muscle	0.27	NA	
Ohio, Sandusky Michigan, Saugatuck Wisconsin, Bayfield	1968-1969	Unspecified	Whole fish and fish livers	N.A.	<0.010	Lucas et al., 1970

NA = Not available.

(2) Concern exists over the possibility that the widespread usage of organomercurial preparations in agriculture in past decades may have increased the mercury content of crops.

(3) Data on nonfish commodities are essential in determining the relative contribution of the various food groups to total dietary intake of mercury.

The most important determinants of mercury concentration in food are the environmental level of mercury in the area where a food is produced and the use of mercury-containing compounds in agricultural and industrial production of the food. Organomercurials have been widely used as seed preservatives and antifungicidal agents sprayed on the foliage of many commercially grown fruits and vegetables, especially fruit trees, potatoes, and tomato plants (Dassani et al., 1975; Hugunin and Bradley, 1975). Foliar application of phenylmercurials produces residue levels in crops four to six times greater than those in untreated controls (D'Itri, 1972).

Recently, usage of mercury in seed dressings and fungicides has been severely curtailed. The use of mercurial pesticides as seed treatments was banned in February, 1976, and later reinstated in August, 1976. Production of these compounds must cease by August 31, 1978, or earlier if the maximum allowed inventory (an estimated 50,000 pounds) is reached. Any pesticides produced before the August deadline will become "existing stocks" which can be sold, distributed, and used until those stocks are depleted (Train, 1976; U.S. Environmental Protection Agency, 1976b). Data presented by Dassani et al. (1975) and Gerdes et al. (1974) suggest that the application of mercury fungicides in the treatment of wheat, tomato plants, and fruit trees is still in practice.

In a "market basket" survey of common fresh fruits and vegetables available in American supermarkets, Gerdes et al. (1974) assessed the impact of the use of mercury in agriculture. As shown in Table 4.4, 19 of 23 common vegetables had mercury concentrations below 0.05 ppm. Okra, cabbage, hot pepper, and string beans had mean mercury concentrations greater than 0.05 ppm. Higher levels were found in those fruits which had been sprayed with mercurial fungicides. The observed differences between commercially obtained peaches (0.063 ppm) and home-grown ones (0.019 ppm) (Table 4.4) may reflect either application of a mercurial fungicide on the commercial peaches or differences in the amount of mercury in the environment in the areas where the peaches were grown.

As shown in Table 4.5, levels in most foods other than fish were below the recommended maximum of 0.05 ppm (Joint FAO/WHO Expert Committee on Food Additives, 1972). Staple foods grown in or available in Michigan were examined by Gomez and Markakis (1974) for total mercury levels. Dairy and poultry products, red meats, cereals, fruits, vegetables, and miscellaneous items, along with many varieties of fish and shellfish, were analyzed (Table 4.5). Mercury concentrations in land-produced foods (not suspected of man-induced contamination) were in the range 0.01 to 0.03 ppm. Fish samples, by comparison, contained larger quantities of

TABLE 4.4. MERCURY CONTENT OF FRESH FRUITS AND VEGETABLES COMMERCIALLY AVAILABLE IN DENTON, TEXAS

Food Product	No. of Samples	Concentration, ppb Mean	Range
Fruits			
Apple, red	2	14	7-25
Apple, yellow	1	86	83-92
Banana	4	85	32-147
Cherry	2	8	4-14
Grape, red	1	113	105-120
Grape, green	1	88	83-92
Grapefruit	1	31	28-34
Lemon	2	110	75-158
Lime	2	111	87-135
Melon	1	8	6-13
Nectarine	2	97	94-100
Orange	1	92	74-102
Peach	4	63	57-73
Peach, homegrown	8	19	16-20
Pear	2	45	0-92
Plum	7	124	47-282
Strawberry	5	48	43-53
Vegetables			
Bell pepper	2	37	1-103
Black-eyed peas	2	5	2-10
Broccoli	1	26	24-27
Cabbage	2	59	27-123
Carrott	3	5	4-6
Cauliflower	2	24	20-46
Celery	2	16	7-23
Corn	2	16	6-33
Cucumber	2	10	2-19
Egg plant	1	47	45-48
Green onion	3	15	12-18
Hot pepper	4	55	50-60
Lettuce	1	20	19-21
Lima beans	2	46	40-50
Lima beans, dried	1	19	17-21
Mushrooms	4	43	32-53
Okra	8	73	57-97
Onion, white	2	44	33-49
Pinto beans, dried	1	17	11-22
Potato	4	34	26-42
Radish	4	4	1-7
Squash	3	3	1-5
String beans	7	51	46-57
Sweet potato	1	21	19-24
Tomato	4	31	20-36
Corn meal	1	98	93-103
Flour, white, bleached	2	103	92-118
Rice	1	87	80-92
Sugar	1	51	49-52

Source: Gerdes et al., 1974.

TABLE 4.5. MERCURY CONTENT OF FOODS (EXCLUDING FISH)

Location[a]	Food Product	No. of Samples	Concentration, ppm		Reference
			Mean	Range	
Kentucky, western	Flour	28	0.003[b]	0.003-0.06	Tanner et al., 1972
	Grains, composite			0.002-0.048	Goldwater, 1971
	Oats		0.012		Dassani et al., 1975
	Rice			0.05-1.0	D'Itri, 1972
	Wheat		7.15		Dassani et al., 1975
	Meats				
	Bacon		0.072		
	Chicken, gizzard		0.007		
	Chicken, liver		0.0009		
	Ham, cooked		0.010		
	Hamburger		0.011		
	Pork, sausage		0.047		
	Weiner		0.008		
	Vegetables and fruits				
	Beans, green		0.017		
	Beets, seed		0.042		
	Carrot			0.00-0.28	Hammons et al., 1975
	Carrot seed		0.030		Dassani et al., 1975
	Onion		0.007		
	Onion			0.00-1.09	Hammons et al., 1975
	Potato		0.012		Dassani et al., 1975
	Tomato, fruit		0.05		
	Tomato, seed		9.45		
	Fresh fruits composite			0.004-0.035	Goldwater, 1971
Michigan	Bread, white	2	0.01	0.005-0.01	Gomez & Markakis, 1974
	Bread, white		0.01		Hammons et al., 1975
	Dairy				
	Cheese, cheddar	2	0.02	0.015-0.03	Gomez & Markakis, 1974
	Cheese		0.08		Goldwater, 1971
	Milk, whole unpasteurized	2	0.01	0.01-0.02	Gomez & Markakis, 1974

TABLE 4.5 (Continued)

Location[a]	Food Product	No. of Samples	Concentration, ppm		Reference
			Mean	Range	
Michigan	Dairy				
	Milk, whole pasteurized	2	0.01	0.005-0.01	
	Milk, spray dried	2	0.02	0.01-0.03	
	Eggs, whole	3	0.03	0.02-0.04	
	Eggs	33	<0.002[b]	<0.002-0.005	Tanner et al., 1972
	Grains				
	Oats, garry grain	1	0.01	0.005-0.01	Gomzz & Markakis, 1974
	Rice, polished grain	2	0.01	0.005-0.01	
	Wheat, dickson grain	2	0.02	0.01-0.025	
	Meats				
	Beef, unspecified	23	0.003	0.002-0.007	Tanner et al., 1972
	Beef, liver	2	0.01	0.01-0.015	Gomez & Markakis, 1974
	Beef, muscle	2	0.01	0.00-0.02	
	Chicken	24	0.003	0.001-0.007	Tanner et al., 1972
	Chicken, liver	2	0.03	0.015-0.03	Gomez & Markakis, 1974
	Chicken, muscle	2	0.02	0.015-0.03	
	Pork, liver	3	0.03	0.02-0.04	
	Pork, muscle	3	0.005	0.00-0.005	
	Salt, noniodized	2	0.06	0.03-0.09	
	Sugar	22	<0.003	<0.003-0.010	Tanner et al., 1972
	Sugar, white	3	0.01	0.005-0.01	Gomez & Markakis, 1974
	Vegetables and fruits				
	Beans, red kidney, dry	2	0.03	0.02-0.035	
	Potatoes, russet, flesh	2	0.01	0.01-0.015	
	Potatoes, russet, unwashed peel	2	0.03	0.02-0.03	
	Potatoes, russet, washed peel	2	0.01	0.01-0.02	
	Tomato, fruit	2		0.00-0.01	
North Dakota	Dairy				
	Milk, whole	155	0.0008	ND-004	Sell et al., 1975
	Egg, melange	405	0.012	ND-0.442	

TABLE 4.5 (Continued)

Location[a]	Food Product	No. of Samples	Concentration, ppm		Reference
			Mean	Range	
North Dakota	Egg yolk		0.062		Goldwater, 1971
	Meats			0.001-0.15	
	Pork, liver	156	0.015	ND-0.304	Sell et al., 1975
	Beef, muscle	453	0.005	ND-0.046	
United States, Location unspecified	Milk, whole		ND[c]		Murthy, 1974
	Milk, whole	32	<0.001[b]	<0.001-0.009	Tanner et al., 1972
	Milk, dry	33	0.010[b]	0.004-0.027	
	Vegetable composite			0.00-0.06	Goldwater, 1971
	Vegetables, fresh composite			0.002-0.010	D'Itri, 1972
	Vegetables, canned composite			0.005-0.025	Goldwater, 1971
	Potatoes			0.006-0.020	D'Itri, 1972.
			0.003[b]	0.001-0.015	Tanner et al., 1972

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[a] Indicates food grown in or available in the state mentioned.

[b] Median rather than mean given.

[c] Not detected or below detection limits.

mercury; however, all samples were below the FDA action level for fish (0.5 ppm).

Concentrations of mercury in animal products and soils of North Dakota were reported by Sell et al. (1975). Average levels in both muscle and liver of beef and swine were considerably below 0.05 ppm (Table 4.5). In fact, only 8 out of 399 beef samples (2 percent) had mercury levels in excess of 0.020 in muscles; only 3 samples of beef liver contained greater than 0.05 ppm. Marked variations were seen among individual eggs produced at the same time and on the same farm, suggesting the possibility that extraneous (nonfeed) mercury was being consumed by free-ranging hens. Similar observations of wide variation in individual beef and swine also suggest that some individuals may have incidental mercury exposures (Sell et al., 1975).

No apparent trends of increasing or decreasing exposure emerge when data from recent studies are compared with those obtained by Stock and Cucuel in 1934 and Gibbs in 1941 (Sell et al., 1975). Mercury levels in key foods of animal origin have apparently remained about the same over the past 30 to 40 years, according to Sell et al. (1975). The analytical techniques used in the earlier studies were undoubtedly less accurate than today's methods and such comparisons should not be accepted uncritically.

MERCURY IN THE MARKET BASKET AND TOTAL DIET

The results of FDA's Total Diet Study, better known as the Market Basket Survey, represents the most comprehensive measurements on the in-situ levels of mercury in foodstuffs (Peyton et al., 1975). Not only do the FDA's Total Diet Studies gather a representative cross-section from 30 markets in 27 different cities but also great care was taken in these studies to prevent sample contamination and to assure a sensitive and accurate analysis (Peyton et al., 1975).

A study by Tanner and Forbes (1975) involved more extensive sampling of food, utilizing the FDA Total Diet Study protocol. This "market basket" approach is common to all of the studies discussed in this section and can be described as follows:

(1) One hundred seventeen food items selected to represent the 2-week diet of an American male 15-20 years old are collected in various geographical locations at regular intervals throughout the year.

(2) Six composites of each of 12 food categories are obtained from 5 regions of the United States.

(3) Foods are weighed, prepared as they are normally eaten, and composited. The composites are slurried and then analyzed.

All commodity groups, except meat, fish, and poultry, contained less than 0.01 ppm mercury (Tanner and Forbes, 1975). Mercury levels as high as 0.041 ppm were found in the meat, fish, and poultry group; but when the composite was analyzed component by component, only the fish component had mercury levels greater than 0.1 ppm. The mercury concentrations for the 11 remaining food groups of the Total Diet Study were well below the 0.05 guideline figure for foods other than fish; mercury levels detected in these foods were generally less than 0.01 ppm. Only the meat, fish, and poultry food group regularly contained measureable amounts of mercury.

Mercury ranked 20th in a list of 33 different residues detected by the FDA's Total Diet Survey during FY 1971 in terms of number of positive occurrences (Manske and Corneliussen, 1974). Mercury residues were found in 10 of 240 composites. All 10 positive composites occurred in meats, fish, and poultry. Among the 10 positive composites, mercury was detected in 7 composites but at levels below quantification, reported as "trace". The range of the positive composites was from "trace" to 0.05 ppm mercury. Separate analyses of the components of this category revealed seafoods as the principal source of mercury.

In FDA's Total Diet Survey from FY 1973, virtually all dietary intake of mercury was found in the meats, fish, and poultry composite (Mahaffey et al., 1975). Mercury was identified in 97 percent of the composites, averaging 0.011 ppm in the composite of meat, fish, and poultry (Table 4.6). Trace amounts were detected in a small percentage of the grains and cereals, root vegetables, and oils, fats and shortening composites. Data from Manske and Corneliussen (1974), Mahaffey et al. (1975), and Carroll et al. (1975) (reporting National Pesticide Monitoring Program data) are presented in Table 4.6. Peyton et al. (1975) assembled FDA data which yield the high (26 ppb-Group II) and low (less than 1 ppb in many food groups, 9 ppb in Group II) median values for any U.S. region (Table 4.7). Maximum reported mercury concentrations for each food group range from 29,400 ppb in red meat to 40 ppb in dairy products.

ESTIMATED DOSAGE

Estimated daily intakes of mercury calculated on the basis of FDA Total Diet Survey data for the years 1971-1974 (Mahaffey et al., 1975) are:

1971 - 2.48 μg/day (Goldwater, 1974)
1972 - 3.85 μg/day
1973 - 2.89 μg/day
1974 - 2.84 μg/day (estimated)

Mahaffey et al. (1975) believe that the estimates presented are quite accurate for the years 1972-1974 and reflect no trends of increasing or decreasing mercury exposure through diet for that period.

Table 4.8 shows the wide variation in dosage of mercury from standard diets in different age-sex groups. Children less than 1 year of age receive the greatest mercury dose on a per weight basis (Peyton et al., 1975).

TABLE 4.6. MERCURY CONTENT IN FOODS: NATIONAL PESTICIDES MONITORING PROGRAM MARKET BASKET DATA

Location	Date[a]	Food Class	Number of Positive Composites[b]	Mean Concentration, ppm	Reference	Remarks
United States Sampling locations throughout U.S.	1971	Total diet study. Positive composites were found in the following categories:			Mahaffey et al., 1975	Mercury concentrations reported as total mercury.
		Food class II Meat, fish and poultry composite		0.011		Detected in 97% of samples.
		Food class III Grains and cereals composite		0[c]		Detected in 3% of samples.
		Food class VII Root vegetables composite		0[c]		Ditto.
		Food class X Oil, fats and shortening composite		0[c]		"
		Food class XII Beverage composites		0[c]		"
National Totals	1971	Food class II Meat, fish and poultry composite		0.02	Manske and Corneluissen, 1974	
Regions						
California, Los Angeles	1971	Food class II Meat, fish and poultry composite	3		Carroll et al., 1975	National Pesticides Monitoring Program initiated mercury analysis in October 1970.
Maryland, Baltimore	1971	Food class II Meat, fish and poultry composite	1			
Massachusetts, Boston	1971	Food class II Meat, fish and poultry composite	4			
Minnesota, Minneapolis	1971	Food class II Meat, fish and poultry composite	0		Carroll et al., 1975	
Missouri, Kansas City	1971	Food class II Meat, fish and poultry composite	1			

[a] Dates in this table are fiscal years.

[b] Number of positive composites out of a possible 30.

[c] Trace count as 0 ppm, but are recorded as positive findings.

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TABLE 4.7 SUMMARY VALUES FOR MERCURY LEVELS IN NONFISH COMMODITIES (ppb)

Type of Commodity	FDA Low	FDA High	Maximums[a]
I Dairy product	(<1) 1	3	40
II Meat, poultry, fish (composite)			
Red meat	9	26	29,400
Poultry			4,000
III Grain and cereal products	(<2) 2	8	400
IV Potatoes	(<1) 1	7.5	230
V + VI + VII (composite) Vegetables	1	2.5	
V Leafy vegetables	(<1) 1	5	570
VI Legume vegetables	(<1) 1	2	--
VII Root vegetables	(<1) 1	2	180
VIII Fruits	(<1) 1	3	260
IX Sugars, fats, oils	3	3	--
X Beverages	1	1[a]	
Beer	1	1[a]	

Source: Peyton et al., 1975

[a] Maximum value reported in the literature where the commodity is known to have been contaminated.

TABLE 4.8. ESTIMATED MERCURY DOSE THROUGH STANDARD DIETS (μg/day)

Type of Commodity	U.S. per capita			Weight: 67.9 kg Male age: 19		Weight: 7.7 kg 1 year		Weight: 64.5 kg Male age: 15-17		Weight 55.5 kg Female Age: 15-17		Weight: 79.1 kg Male age: 35-54	
	FDA			FDA		FDA		FDA		FDA		FDA	
	Low	High	Other	Low	High	Low	High	Low	High	Low	High	Low	High
I Dairy products	0.44	1.82	3.08	0.89	2.66	0.80	2.40	0.70	2.10	0.48	1.44	0.28	0.84
II Meat, poultry, fish 85% CH_3Hg^+	2.90 (2.46)	8.37 (7.11)	24.15 20.52	1.93 (1.64)	5.56 (4.73)	0.45 (0.38)	1.30 (1.13)	2.47 (2.10)	7.15 (6.08)	1.80 (1.53)	5.20 (4.42)	2.70 (2.30)	7.80 (6.63)
III Grain and cereal	0.40	1.62	3.02	0.87	3.50	0.05	0.20	0.25	1.10	0.17	0.69	0.22	0.90
IV Potatoes	0.17	1.26	0.84	0.18	1.37	0.01	0.04	0.09	0.67	0.05	0.38	0.08	0.56
V+VI+VII Vegetables	0.20	0.49	3.37			0.01	0.03	0.08	0.19	0.08	0.19	0.08	0.20
V Leafy vegetables				0.05	0.23								
VI Legume vegetables				0.07	0.14								
VII Root vegetables				0.16	0.32								
VIII Fruits	0.16	0.48	2.74	0.29	0.87	0.02	0.05	0.10	0.30	0.08	0.24	0.10	0.30
IX Sugars, fats, oils	0.58	0.58	9.07	0.41	0.41	0.04	0.04	0.29	0.29	0.19	0.19	0.26	0.26
X Beverages - Other	0.50	0.50	0.50	1.20	1.20	0.01	0.01	0.43	0.43	0.39	0.39	0.80	0.80
Beverages - Beer												0.14	0.14
Total Hg dose per person,													
μg/day	5.35	14.62	46.77	6.05	16.26	1.39	3.89	4.41	12.23	3.24	8.72	4.66	11.80
μg/μg-day				0.089	0.239	0.180	0.503	0.680	0.189	0.058	0.157	0.059	0.149
Methylmerdury dose per person, μg/day	2.46	7.11	20.52	1.64	4.73	0.38	1.13	2.10	6.08	1.53	4.42	2.30	6.63
μg/kg-day				0.024	0.070	0.049	0.146	0.033	0.094	0.027	0.079	0.029	0.084

Source: Peyton et al., 1975.

The U.S. per capita estimated mercury dose in standard diets reported by Peyton et al. (1975) in Table 4.8 ranges from 5.35 to 14.62 μg/day. Dietary mercury exposure for the upper 10, 5, 1, and 0.1 percent of the population in terms of fish consumption is shown in Table 4.9 (Peyton et al., 1975). Persons belonging to Weight Watchers or others having special diets which substitute fish for meats are expected to receive above average quantities of mercury in their diets. Peyton et al. (1975) have tabulated these dosage data in Table 4.10.

TABLE 4.9. MERCURY EXPOSURE FROM THE DIET OF FISH EATERS

Fraction of Population Exceeding	Grams per day of Purchased Fish	Mercury Exposure from Purchased Fish[a]	Mercury Exposure from Total Diet
10%	26	4.2 g/day	12.3 g/day
5%	38	6.1	14.0
1%	77	12.3	19.9
0.1%	165	26.4	33.1

Source: Peyton et al., 1975.

[a] Assumes that the types of fish consumed are the same as for the average population in the Market Facts survey.

TABLE 4.10. MERCURY EXPOSURE FROM THE DIET OF WEIGHT WATCHERS

Source	Grams per day Consumed	Mercury Exposure, μg
Shrimp	16.3	1.0
Salmon	16.3	0.7
Scallops	16.3	0.5
Tuna	16.3	5.8
Other fish	32.6	5.2
Total fish	97.8	13.1
Other meats	114.0	1.1
Other food		4.6
Total mercury		18.8

Source: Peyton et al., 1975.

5. MERCURY IN MAN

Nordberg (1976) has divided mercury compounds into three functional categories on the basis of toxic properties: (1) mercury vapor, (2) inorganic mercury salts and phenyl- and methoxyethylmercuric salts, and (3) methyl- and ethylmercuric salts. This review follows this same classification scheme.

MERCURY VAPOR

Persons employed in the manufacture of scientific instruments, electrical meters, alkalies and chlorine, mercury vapor lamps, amalgams, solders, and jewelry are potentially exposed to mercury vapor (Browning, 1969), and concentrations of mercury vapor occur in laboratories of chemistry, physics, dentistry, and medicine (Casarett and Doull, 1975).

Mercury vapor is absorbed primarily through the lungs and respiratory tract, although small amounts may also be absorbed percutaneously (Nordberg, 1976). Gastrointestinal absorption after oral ingestion is minimal. In contrast, absorption of an inhaled dose by the lung has been estimated as 75 percent complete (Clarkson, 1975). After absorption, elemental mercury is transported by the blood where it may be either oxidized to the divalent ion in the red blood cells and tissues or may remain dissolved in the elemental form in the blood and transported in this form across the blood-brain barrier and oxidized later in the brain tissue (Casarett and Doull, 1975). Most of the absorbed mercury is transported within the first few days to the kidney and also to a lesser extent to the liver. After repeated exposure, mercury steadily accumulates in the kidneys where it is bound by sulfhydryl groups. At least 1 percent is absorbed by the brain (Nordberg, 1976). Experiments in primates as well as human autopsy findings have shown a differential pattern of distribution within the brain (Glomski et al., 1973).

Primate studies suggest that the biological half-life of mercury in the brain is probably on the order of years (Nordberg, 1976). The retention in the kidney is considerably shorter than that in the brain; however, retention rates in the kidney are not uniform. Instead, the kidney behaves as a multicompartmental system; at least one compartment shows rather long retention with biological half-life exceeding 1 month (Nordberg, 1976).

These differential retention rates within the several "compartments" are poorly understood. Clarkson (1975) has estimated a whole-body elimination half-life of 58 days from a study of human volunteers who inhaled radioactive mercury vapor.

The primary means of excretion of mercury are feces and urine, but smaller amounts may also be eliminated in sweat, milk, and hair. At low doses, the majority of body burden is eliminated via bile and feces. As dosage increases, however, a larger proportion is eliminated in the urine (Nordberg, 1976).

No diagnostic index medium (i.e., blood, hair, urine, etc.) has been found which parallels the concentration of mercury in the brain from exposure to mercury vapor. Neither blood nor urine accurately reflects brain levels after exposure to mercury vapor and there is no simple correlation between these parameters (Nordberg, 1976). Likewise, there is no suitable index media to reflect lung levels.

Approximately 210,000 pounds of mercury per year are used in dentistry. Each practicing dentist uses, on the average, 2.5 pounds of mercury annually in the preparation of dental amalgam restorations. Because the exposure of the dentist and his assistants to this quantity of mercury suggests the potential for toxicity, Stevens et al. (1972) conducted measurements of mercury vapor at the Naval Dental Clinic (NDC) at the Washington Navy Yard, the dental clinic at the Naval Graduate Dental School (NGDS), and the staff dental clinic at the National Naval Medical Center (NNMC). Atmospheric concentrations of mercury in air at each of the facilities were measured throughout the day, at varying distances from the floor corresponding to the breathing zone of the patient and the operator. Additional measurements were made during vacuuming in the pertinent carpeted areas, trituration of amalgam with the amalgamator, and on a dental assistant's hands before and after washing. Urine samples from assistants working in the room with the highest concentration (the staff clinic) were compared with control samples from persons working in the same facility but having no known exposure to mercury. Table 5.1 shows mercury vapor concentrations in dental operating rooms at the three naval dental facilities. Readings at different heights did not differ significantly. Values for all dental operating rooms tested ranged from a low of 0.001 ppm (0.012 mg/m^3) to a high of 0.024 ppm (0.200 mg/m^3). The highest readings were obtained in the staff clinic during vacuuming of a carpet in a room where a mercury spill had occurred 4 months previously. The concentration was recorded at 0.004 ppm (0.035 mg/m^3) prior to vacuuming, peaked to 0.024 ppm (0.1999 mg/m^3) during vacuuming, and immediately decreased to 0.0096 ppm (0.080 mg/m^3) when the vacuuming stopped. The level remained above the threshold limit value of 0.0060 ppm (0.05 mg/m^3) for a total time of 25 minutes. Stamping the foot on the contaminated carpet was followed by a peak reading of four times the threshold limit value, and peaks of about twice that amount were recorded when the amalgam was triturated and also when a drawer containing the amalgamator, mercury bottle, and pellets was opened. Following each of these actions, the concentration decreased below the threshold limit value within 5 seconds. Urinary mercury levels paralleled concentrations in air; the highest mean urine mercury level of 0.0112 ppm was obtained for the three persons working in the room at the staff clinic where the mercury vapor in air was also highest. The observed elevations in urinary mercury levels are indicative of absorption well in excess of the normal population. A study by Gutenmann et al. (1973) revealed that 89 percent of hair samples obtained from a survey of 115 New York dentists

TABLE 5.1. MERCURY VAPOR CONCENTRATION IN NAVAL DENTAL OPERATING ROOMS[a]

Facility	Number of Readings	Concentration, ppm (mg/m^3)	
		Mean	Range
Navy yard, NDC	28	0.0031 (0.026)	0.002-0.0096 (0.017-0.080)
Clinic, NGDS	30	0.0047 (0.039)	0.001-0.011 (0.012-0.090)
Staff clinic, NNMC	34	0.0067 (0.056)	0.003-0.024 (0.022-0.200)

Source: Stevens et al., 1972.

[a] Conversion formula used to convert mg/m^3 to ppm for air measurements:

$$mg/m^3 = \frac{\text{ppm (molecular weight mercury, 200.59)}}{24.04}$$

were above the 0.01 to 2.5 ppm range observed in persons not exposed to other than "normal" sources of mercury (Gutenmann et al., 1973). However, correlation between number of years in practice and hair levels was not significant.

Smith et al. (1973) studied the effects of mercury in 642 workers exposed to varying levels of mercury vapor in the manufacture of chlorine. Time-weighted exposure averages for mercury in air were determined at numerous sampling points and the amount of time spent by each employee in the different locations was specified, permitting accurate assessment of individual exposures. The most important finding was the existence of a close correlation ($P<0.01$) between time-weighted averages of mercury in air, blood, and urine. Data from the study are presented in Figures 5.1 and 5.2. Such findings suggest that under chronic exposure conditions, urinary excretion quite accurately reflects exposure to mercury, at least on a group basis. A literal interpretation of the regression lines indicates that an air concentration of 0.012 ppm (0.1 mg/m^3) corresponds to a blood level of 0.060 ppm and 0.260 ppm in urine.

MERCURIC MERCURY

Exposure to potentially toxic amounts of mercuric salts occurs almost exclusively in industrial settings. In the past, however, ignorance of the toxic effects of mercuric salts exposed a much wider proportion of the population, not only through occupational exposures (especially in the production of felt) but also through medicinal preparations, cosmetics, and poisons. Recently, the most common uses of mercuric salts have been in the paper and pulp industry in the production of antifouling paints, and to a lesser extent in the preparation of drugs, disinfectants, and agricultural products. Mercuric salts are absorbed by the body primarily through inhalation and dusts and ingestion, but significant percutaneous

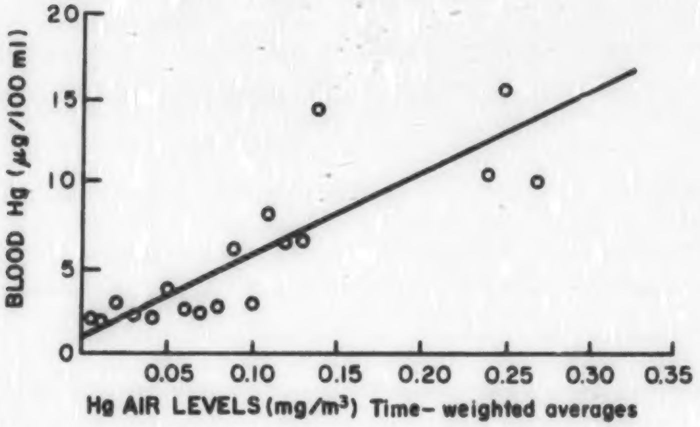

Figure 5.1. Mean blood levels of mercury versus time-weighted averages of mercury in air (Smith, 1972)*

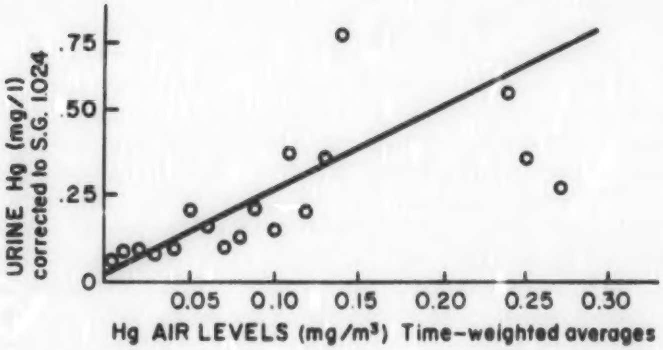

Figure 5.2. Urine levels of mercury versus time-weighted averages of mercury in air (Smith, 1972)*

absorption has also been documented (Casarett and Doull, 1975). Generally, where exposure to inorganic dust occurs, it is in combination with mercury vapor (Environmental Health Resource Center, 1973). Inorganic forms of mercury taken orally are not absorbed very quickly by the body. Only about 2 percent of orally administered inorganic compounds is absorbed (Clarkson, 1972). Once absorbed, approximately 50 percent of the mercury is transported by the blood plasma and is rapidly excreted by the urine (Friberg and Vostal, 1972). Following injection of a mercuric salt in animals, only about 25 percent of total blood mercury is bound to the erythrocytes. Comparable values for mercury vapor were 67 to 68 percent, for arylmercury, 50 percent, and for methylmercury, 90 percent, bound to red blood cells. (Environmental Health Resource Center, 1973). In the blood, the soluble inorganic mercurial is first attached to δ-globulins and erythrocytes but later shifts to albumin from which it is redistributed to the tissues with a biological half-life of about 15 days and is, therefore, more amenable to excretion from the body in urine. Consequently, less is stored in the organism following exposure to inorganic salts, relative to the forms mentioned above (Friberg and Vostal, 1972). The amount and rate of absorption of aerosols of mercury salts in the respiratory tract have not been well established, but is probably less than that of mercury vapor (Environmental Health Resources Center, 1973). Following acute exposure to mercuric salts, the highest tissue concentrations are found in the kidney and the liver. Inconsistent results concerning the relative mercury concentrations of the other organs have been reported, with most studies showing minimal or nonexistent levels in the brain (Nordberg, 1976). Within a few hours after administration, the mercury is found in human and animal tissues in the following approximate order of decreasing concentration: pancreas, kidney, liver, spleen, blood, bone marrow, upper respiratory and buccal mucosa intestinal wall (especially colon), skin, salivary glands, heart, skeletal muscle, brain, and lung (Goodman and Gilman, 1975). There is also some indication that mercuric salts can be stored in bones (Goodman and Gilman, 1975). Blood levels are high immediately after exposure, but they diminish rapidly with time (Environmental Health Resource Center, 1973). Inorganic mercury is slowly released from tissues, especially the intestines and muscles (Friberg and Vostal, 1972). The favored excretion route following absorption of mercuric salts is the urine, followed by the feces (Browning, 1969). Smaller amounts are also excreted in the hair, milk, saliva, and sweat (Nordberg, 1976).

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*Reprinted from ENVIRONMENTAL MERCURY CONTAMINATION, Hartung and Dinman. Ann Arbor Science Publishers, Inc., 1972.

Nordberg (1976) has reported studies on the biological half-life of inorganic mercury compounds in human volunteers given an oral tracer dose. That estimated for mercury in blood was 20 days, while that of the whole body was estimated at about twice as long. Other studies reported by Nordberg (1976) have estimated a whole-body biological half-life ranging from 20 to 60 days for human adults. About 7 percent of the total administered dose was excreted during this time. Animal experiments suggest that half-lives in kidney and brain are considerably longer than those of the whole body. Animal experiments also indicate the possibility that blood and urine levels may be an appropriate index of kidney concentration (Nordberg, 1976). Regardless of the mode of exposure, the kidney is the critical organ.

The organomercurials, methoxyethyl- and phenylmercury, are discussed in this section because their behavior in biological systems resembles that of the inorganic mercury salts. Both types of compounds appear to be rapidly metabolized to inorganic mercury, which is then eliminated (Friberg and Vostal, 1972).

Phenylmercuric acetate (PMA) is used as an eradicating fungicide and selective herbicide, especially on golf courses (Berg, 1976). Methoxyethylmercurials are also used as fungicides; currently, they are replacing methylmercury in many agricultural fungicide preparations (Nordberg, 1976).

The absorption and distribution patterns of phenyl- and methoxyethylmercurials are remarkably similar to those of inorganic mercurials (Casarett and Doull, 1975). After exposure, both organic compounds are deposited in the liver and other tissues where they are converted into inorganic mercury (Friberg and Vostal, 1972). Phenylmercurials are hydroxylated on the ring, conjugated, and then decomposed to inorganic mercury and phenol conjugates (Goodman and Gilman, 1975). The methoxyethylmercurial shows a greater affinity for red blood cells than inorganic, yet much less than methylmercury.

ALKYLMERCURIALS

The short-chain ethyl- and methylalkylmercurials have been used to prevent seedborne diseases in cereal grains, and mercury fulminate is used in the production of explosives (Browning, 1969). Methylmercury compounds are much more readily absorbed by the gastrointestinal tract than inorganic forms. Both human and animal experiments have shown 90 to 100 percent gastrointestinal absorption of methylmercury, while comparable absorption of inorganic salts is only about 50 percent (Zepp et al., 1974). Studies on human volunteers given a single tracer dose of methylmercury revealed the following metabolic characteristics (Clarkson, 1975):

(1) Absorption efficiency equals 95 percent of oral intake.

(2) One percent of daily intake was recovered from 1 liter of whole blood.

(3) Whole body elimination half-life ranged from 52 to 93 days.

(4) Half-life clearance in blood was 45 to 105 days.

(5) A hair-to-blood concentration ratio of 250:1 was reported.

Methylmercury is well absorbed through the skin and lungs (Casarett and Doull, 1975). The absorption of inorganic or organic mercury vapor through the lungs poses a special problem because vapor exposure produces accumulation of mercury in the brain far in excess of that found after an equivalent dose of inorganic mercury is administered either orally or intravenously (D'Itri, 1972).

Studies of tracer doses of methylmercury showed that the liver and head together accumulated 60 percent of the total body burden. The liver accounts for 50 percent and the head, 10 percent, of the radioactive dose. Probably the brain accounts for 90 percent of the head burden (Nordberg, 1976). Distribution also differs in that the levels of mercury in the kidney, brain, and blood are generally within a two- or threefold range of each other after exposure to short-chain alkylmercurials; differences observed with other types of mercury may be in the 100-fold range (Casarett and Doull, 1975). Methylmercury is preferentially accumulated in the red blood cells; more than 90 percent of methylmercury present in blood is bound to red cells (Clarkson, 1972). The superior biological stability of alkylmercurials is shown by their resistance to degradation to inorganic mercury which can then be eliminated from the body. The 70-day biological half-life demonstrates slower excretion of methylmercury than all of the other forms (Friberg and Vostal, 1972). Excretion of mercury after oral administration of methylmercury is chiefly in the feces, although smaller amounts are also excreted in the urine, hair, and milk (Environmental Health Resource Center, 1973). In man, urinary excretion is slow at first but accelerates during the first 30 days after exposure (Aberg et al., 1969).

Subcutaneous and intravenous injections produce more rapid excretion in both urine and feces; however, the favored route for inorganic mercury is urine, while that for organic is the feces (Browning, 1969). Few comparable data on the metabolism of ethylmercury are available; however, it seems quite similar to methylmercury in this respect (Nordberg, 1976).

A mean biological half-life for whole-body clearance ranging from 52 to 93 days with a mean value of 76 days was obtained from tracer studies of volunteers given oral doses of ^{203}Hg (Miettinen, 1973). Miettinen et al. (1971) estimated a mean biological half-life in red blood cells of 50 days, with a standard deviation of 7 days. In a study of persons exposed to methylmercury through fish consumption during and after varying degrees of exposure, Birke et al. (1972) observed a half-life of methylmercury of 99 to 120 days in blood cells, 47 to 130 days in plasma, and 33 to 120 days in hair after correction for background levels in mercury. Figure 5.3 shows decay curves in six subjects after the dietary change to low fish intake or to mainly ocean fish, or both. A methylmercury biological half-life of 72 days (range 35 to 189 days) was found for the hair of persons who had ingested methylmercury-treated grains (Al-Shahristani and Shihab, 1974).

MERCURY LEVELS IN HUMAN TISSUES

Mercury levels in tissues of both normal and exposed humans show considerable variation, but the highest levels are found most frequently in the kidney and liver (Environmental Health Resource Center, 1973). Mercury levels from autopsy tissues (lung, liver, and kidney) from two geographical areas showed 95 percent of the population having less than 3.0 ppm in kidney and 0.2 ppm in liver and 99 percent having less than 1.0 ppm mercury in the lung (Stein et al., 1974).

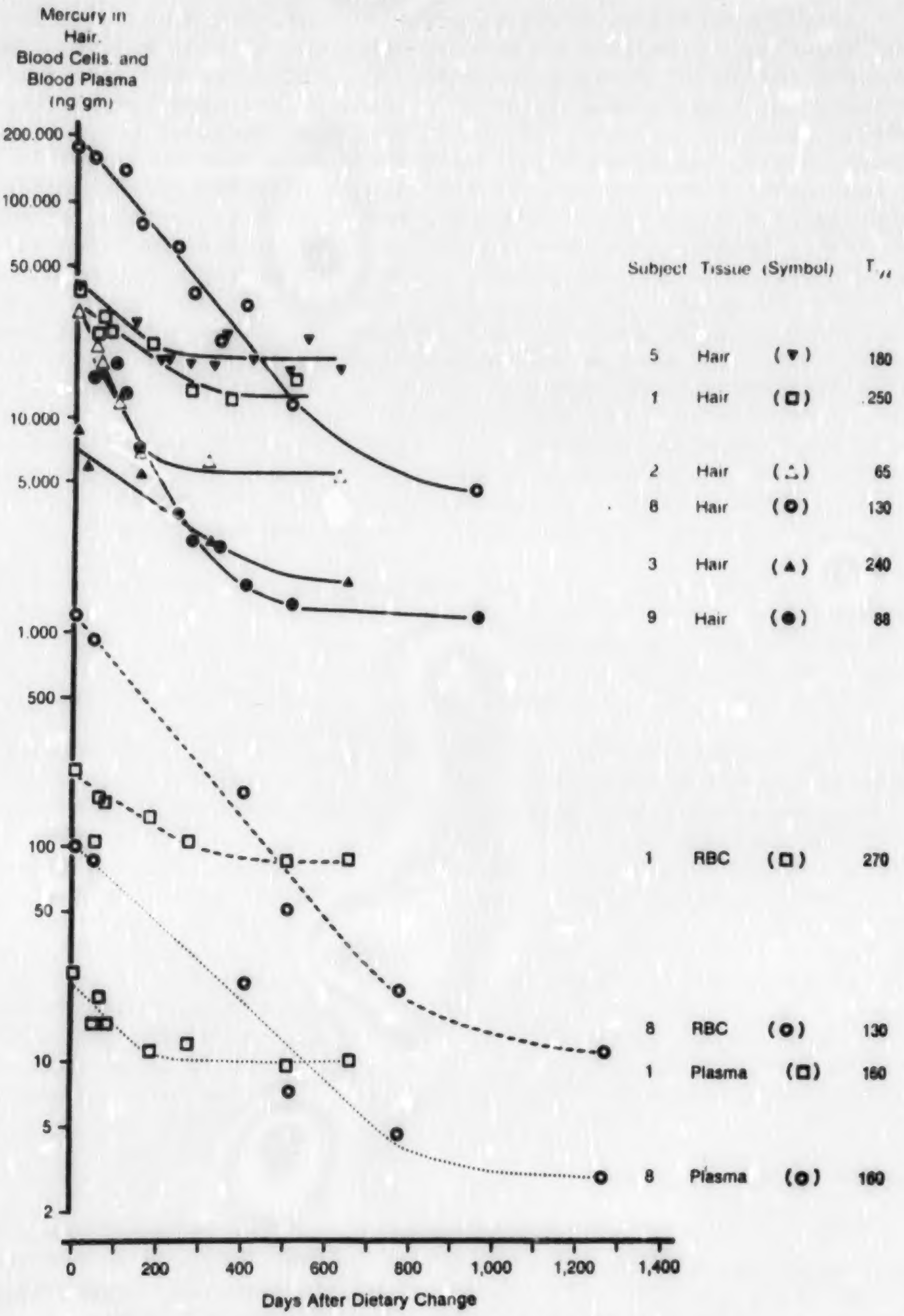

Figure 5.3. Elimination of total mercury from hair, blood cells, and plasma in six subjects (Birke et al., 1972).

Table 5.2 summarizes data obtained in the United States between 1970 and 1974. Over 70 percent of assays, regardless of organ or age, had a mercury burden of less than 0.25 ppm wet weight (Mottet and Body, 1974). They reported: (1) no statistically significant increase in mercury burden occurred with age, indicating that past environmental exposures did not exceed the capacity of the body to eliminate mercury; (2) elimination at present levels of exposure equalled intake; and (3) a strong suggestion that the urban population had a somewhat greater mercury burden than the rural. The authors concluded that the general population had a mercury burden below 1 to 2 ppm in kidney, 0.25 to 0.75 ppm in liver, and less in other tissues.

Mercury was detected in 76 percent of all autopsy tissues examined by Gabica et al. (1975). The specimens were obtained from residents of three geographic regions of Idaho. About 3.5 times more mercury occurred in kidney tissue than in liver; kidney levels were about ten times that in the brain. The highest levels were found in samples from persons from southwest Idaho where natural mercury deposits are found. Glomski et al. (1973) found a pattern of selective accumulation within the brain in a study of persons without known pathological exposure to mercury. As shown in Table 5.2, the highest levels were generally found in the cerebellar cortex, while the white matter of the cerebral hemispheres consistently had the lowest or next lowest values in all individuals.

The upper limit of "normal" mercury levels in urine is 0.20 to 0.25 ppm. Seventy-five percent of the normal population have less than 0.005 ppm in blood and 95 percent have less than 0.04 ppm (Environmental Health Resource Center, 1973). Mercury levels in blood, urine, and hair vary according to exposure.

Table 5.3 presents data from several studies of hair mercury levels in normal persons and others with known exposure. Benson and Gabica (1972) detected mercury in all 1,000 samples of hair from Idaho residents. Their study revealed no correlation between fish consumption and other common sources of exposure to the measured levels. The mean concentration was 4.18 ppm and mean levels for males and females were 2.45 and 5.90 ppm, respectively. The authors suggest sexual differences in hair may reflect hormonal or biochemical influences.

Nord et al. (1973) sampled hair from residents of industrialized Pasadena, California, and the nonindustrialized Los Alamos, New Mexico, area. As shown in Table 5.3, hair from women from the Pasadena area showed a mean concentration of 29.6 ppm compared with 20.1 ppm in hair of women from Los Alamos. The authors state that their findings are higher than other values reported in the literature, but they offered no specific explanation. Environmental exposure indices (as measured in dustfall and house dust) were significantly associated with values for scalp-hair mercury in both children and adults (Creason et al., 1975). Eads and Lambdins' (1973) study, however, did not show significant differences in mercury levels in hair from persons in a polluted area (Port Arthur, Texas) and literature values.

TABLE 5.2. MERCURY CONTENT OF SELECTED HUMAN TISSUE (AT AUTOPSY)

Location	Date	No. of Samples	Organ and Site	Age and Sex	Concentration, ppm	
					Mean	Range
Idaho[a]						
Statewide	1973-1974	28	Brain	Males, all ages	0.06	0.0-0.25
		14		Females, all ages	0.10	0.0-0.94
		58	Kidney	Males, all ages	1.06	0.0-15.70
		36		Females, all ages	1.06	0.0-12.50
		61	Liver	Males, all ages	0.15	0.0-2.11
		45		Females, all ages	0.53	0.0-5.80
New York[b]						
Buffalo and adjacent Great Lakes area	NA	6	Brain, frontal lobe cortex	Adults, both sexes	0.377	0.3-1.69
		7	Brain, cerebellar cortex	Ditto	0.659	0.08-1.85
		5	Brain, medulla	"	0.354	0.04-1.29
		7	Brain, pons	"	0.419	0.05-1.66
		6	Brain, midbrain	"	0.288	0.06-1.20
		6	Brain, thalamus	"	0.323	0.04-1.47
		7	Brain, white matter	"	0.0786	0.02-0.15
Washington (State)[c]	1970-1972	60	Brain, cerebellum	Composite sexes	0.132	0.006-0.965
		61		and ages	0.081	0.008-0.470
		57	Heart	Ditto	0.102	0.012-0.704
		95	Kidney	"	0.757	0.006-6.40
		95	Liver	"	0.250	0.008-1.43
		77	Lung	"	0.251	0.0-2.763
		69	Muscle, unspecified	"	0.126	0.0-0.954
		32	Pancreas	"	0.065	0.007-0.511
		60	Skin	"	0.193	0.004-1.275
		59	Spinal cord	"	0.087	0.010-0.083
		41	Spleen	"	0.122	0.012-1.205

[a] Source: Gabrica et al., 1975.
[b] Source: Glomski et al., 1973.
[c] Source: Mottet and Body, 1974.

TABLE 5.3. CONCENTRATION OF MERCURY IN HUMAN HAIR--PERSONS OF LIMITED AND KNOWN EXPOSURE

Location	Date	No. of Samples	Age and Sex	Concentration, ppm		Reference
				Mean	Range	
California						
Pasadena	1969	99[a]	Adult, females	29.6	5.0-410.-	Nord et al., 1973
Idaho						
Statewide	1971	1,000	Composite sexes and ages	4.18	0.12-139.0	Benson and Gabica, 1972
			Ages 1-10, male	2.04	0.26-8.0	
			Ages 1-10, female	3.21	0.56-12.0	
			Ages 11-20, male	3.28	0.13-107.0	
			Ages 11-20, female	6.99	0.25-104.0	
			Ages 21-40, male	2.01	0.33-17.6	
			Ages 21-40, female	4.92	0.24-43.8	
			Ages 41-60, male	2.37	0.20-100.0	
			Ages 41-60, female	7.64	0.26-139.0	
			Ages ≥61, male	2.55	0.12-24.6	
			Ages ≥61, female	6.72	0.64-120.0	
			All ages, male	2.45	0.12-107.0	
			All ages, female	5.90	0.24-139.0	
New Mexico						
Los Alamos	1969	147[b]	Adult, females	20.8	5.0-680.0	Nord et al., 1973
		80	Adult, males	20.1	NA[c]	
New York						
Central	NA	115	Adult, males	NA	1.0-34.0	Gutenmann et al., 1973
Metropolitan New York City	1971	280	Ages 0-15, both sexes	0.672[d]	0.048-11.30	Creason et a , 1975
		203	Ages ≥16, both sexes	0.774[d]	0.050-14.00	
Texas						
Port Arthur	NA	19	Males	5.4	0.2-12.4	Eads and Lambdin, 1973
		19	Females	5.5	0.1-139.0	

[a] Ninety-nine samples were actually taken; however, 1 sample containing 410 ppm was not included in computation of mean, leaving 98 samples.

[b] One hundred forty-seven samples were actually taken; however the sample containing 680 ppm was not included, leaving 146 samples.

[c] NA = not available.

[d] Geometric mean.

The absorption, accumulation, and excretion of methylmercury in man has been extensively studied in experimental settings as well as in "natural" exposures such as the epidemics of methylmercury poisoning at Minamata, Niigata, and Iraq. Clarkson (1975) has utilized a mathematical model of methylmercury metabolism to investigate relationships between exposure levels and various indicator media such as hair, urine, and blood. Nordberg (1976) has summarized the relationships discovered thus far as follows:

- A specific relationship exists between levels in each organ and total body burden of methylmercury.
- Definite relationships exist among the levels of methylmercury in various organs.
- Elimination is correlated with body burden, i.e., a specific fraction of body burden is eliminated per unit of time.
- A linear relationship exists between daily dose and mercury levels in blood and hair.
- Levels in blood and hair are related in linear fashion, with the hair levels about 250 to 300 times whole blood levels. Thus, hair is of greatest potential value as an index media for exposure to methylmercury. Also, hair allows recapitulation of past exposure.
- At levels below which symptoms of toxicity occur, accurate estimation of brain levels may be made on the basis of blood levels.
- Urine values are of little value in estimating body burden because not only are there low levels of methylmercury present in the urine but also the relatively larger proportion of inorganic mercury present in urine introduces analytical difficulties.

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